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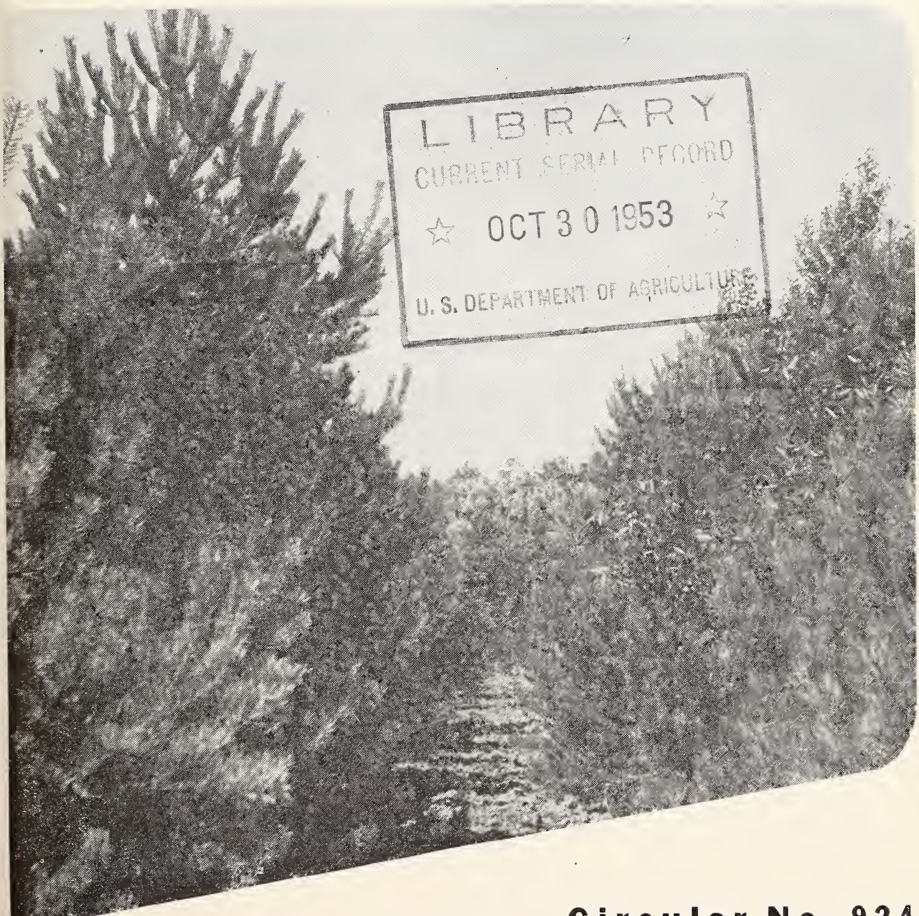
31-YEAR RESULTS in Growing Shelterbelts on the Northern Great Plains



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UNITED STATES DEPARTMENT OF AGRICULTURE

Thirty-One-Year Results in Growing Shelterbelts on the Northern Great Plains

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Contents

INTRODUCTION

A farmer undertaking to establish a shelterbelt anywhere on the northern Great Plains, an area most of which is almost treeless in nature and which has climatic conditions unfavorable for the growth of trees, needs very reliable advice on what trees and shrubs to plant, how to plant them, and how to take care of them. Advice on these subjects is offered by the United States Northern Great Plains Field Station on the basis of tests extending over a

[1] The author wishes to acknowledge the assistance of Gene S. Howard, agricultural aid, in compiling and assembling data for tables and figures and that of William G. Clark, clerk, who coded the field-sheet data for analysis purposes.

period of 35 years. The station began shelterbelt experiments on its home grounds, at Mandan, N. Dak., in 1914. In 1916 it began testing promising shelterbelt species and methods in cooperation with farmers over an area of more than 200,000 square miles in North and South Dakota, Montana, and Wyoming. This report summarizes what was learned in the first 31 years of the cooperative project about selecting a shelterbelt site, selecting tree and shrub species for use in different parts of the belt, how many rows the belt should have, and how the trees and shrubs should be spaced. It gives figures on growth in height and in crown spread, resistance to cold, and survival for 12 species of deciduous trees, 8 of coniferous trees, and 8 of deciduous shrubs. Advice given here enables farmers in most parts of the northern Great Plains to set out trees and shrubs in shelterbelt formation with fair assurance that their efforts will result in long-lasting protection to farm buildings, livestock, orchards, and gardens.

Tree planting for protection from wind and snow has been practiced on the northern Great Plains since the early days of settlement. Federal and State Governments encouraged it in the early days by enacting various laws which benefited planters who complied with certain requirements. A Dakota Territory law of 1869 exempted from taxation 40 acres of land on any farm, and all improvements not exceeding $1,000 in value on that acreage, provided trees were planted on 5 acres. Other laws provided bounties for each acre of trees planted or offered title to 160 acres of land to homesteaders who planted 40 acres of trees and protected them for 10 years. Many of the early tree plantings failed, principally because the settlers lacked reliable information on suitable species and methods.

Among the pioneer experimenters in planting trees on the northern Great Plains was the South Dakota Agricultural Experiment Station, at Brookings, which planted blocks of 20 species or varieties in 1889 to study hardiness, growth, and survival. L. C. Corbett *(3)*,[2] horticulturist, reported in 1895 that some of the species, particularly European larch, black walnut, bur oak, and green ash, were very susceptible to late spring frosts. In 1897 the same author *(4)* reported the results of a mail survey of the culture of forest trees in South Dakota; suggested that with regard to tree planting the State be divided into an eastern and a western part, separated by the Missouri River, and the eastern part be divided into at least three sections; and listed trees suited to four sections of the eastern part and to the Black Hills area.

In 1896 there appeared in the Department of Agriculture Yearbook an article by Charles A. Keffer entitled "Tree Planting in the Western Plains" *(13)*. If the recommendations offered in this article had been followed, the percentage of later failures would not have been so great as it was.

Experimental tree plantings on both irrigated and nonirrigated land were made at the United States Belle Fourche Field Station,

[2] Italic figures in parentheses refer to Literature Cited, p. 55.

in western South Dakota, in 1909. Results from these plantings were not published until some 25 years later.

Railway companies—the Northern Pacific, the Great Northern, and the Minneapolis, St. Paul & Sault Ste. Marie—made extensive tree plantings on the northern Great Plains in the early years to protect their lines from snow. Some of these plantings are thriving satisfactorily in North Dakota today, but many of them failed. A nursery established by one of the companies to grow stock for making protective plantings in North Dakota and Montana was abandoned in 1917.

Shelterbelt work begun at Mandan in 1914 included tests of a large number of trees for hardiness and growth characteristics and studies to find the best methods of growing the trees. The cooperative program on farms, begun in 1916, consisted in testing further the species and methods which had given promise in the station tests and demonstrating these species and methods to farmers.

This publication reports the results of the cooperative project for the period ending with 1946.

PROJECT AREA

Extent and Topography[3]

The area covered by the cooperative shelterbelt program (fig. 1) comprises Rolette, Pierce, Wells, Kidder, and Emmons Counties and all counties to the west of them in North Dakota; Campbell, Walworth, Potter, Sully, Hughes, Lyman, and all westward counties in South Dakota which lie north of the White River, including Custer County; the part of Montana lying east of the foothills of the Rocky Mountains; and Crook, Weston, Campbell, Johnson, Sheridan, Big Horn, Washakie, Hot Springs, and Park Counties in Wyoming. Very few cooperative plantings were made in the last-named four counties in Wyoming and in the counties having mountainous topography in the southwestern part of the Montana area. The area as a whole extends about 600 miles east and west and 400 miles north and south.

The glaciated part of the northern Great Plains (fig. 1) extends west of the Missouri River in North and South Dakota for distances ranging to 60 miles. A thin layer of glacial drift is found on the west or south side of the river; on the east or north side there is a thick deposit, having a gently rolling to rough surface. The Altamont Moraine, which marks the limit of the Wisconsin ice sheet, extends across North Dakota in a line more or less paralleling the course of the Missouri River at distances of 10 to 50 miles to the north and east. This moraine forms a rough belt of hills and ridges averaging 12 to 15 miles in width. Many undrained hollows and depressions within it are occupied by lakes

[3] Descriptions of surface features of the area are taken in part from earlier publications *(23, 14)*.

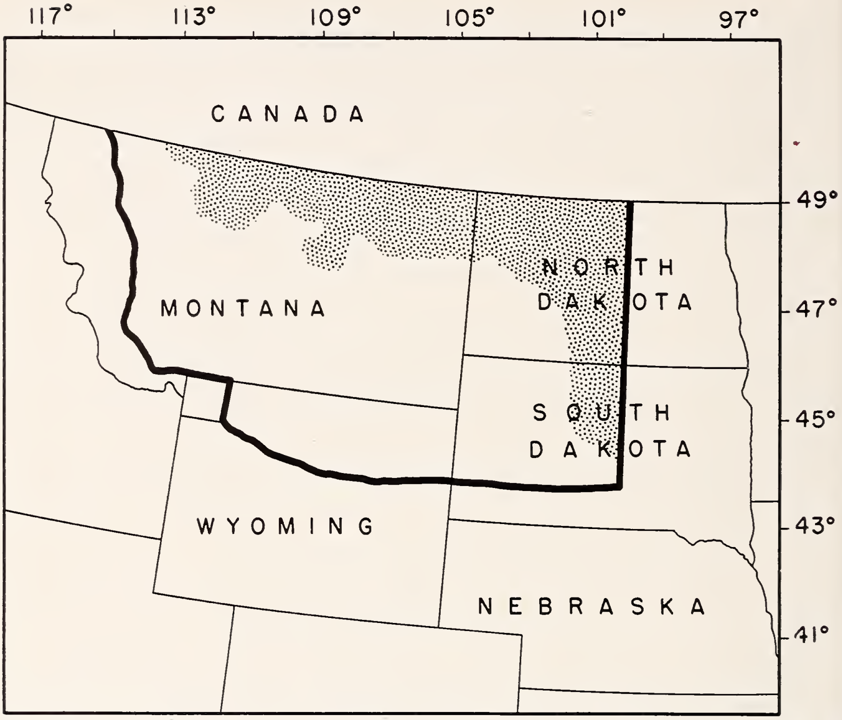

FIGURE 1.—The heavy line indicates approximately the geographic extent of the cooperative farm-shelterbelt project of the Northern Great Plains Field Station. Stippling indicates the glaciated part of the project area.

and marshes. Most of the glaciated area in Montana is well-drained rolling prairie or level stretches of benchland.

The unglaciated part of the area is composed of rolling prairie and broad sweeping valleys drained by the tributaries of the Yellowstone and Missouri Rivers. Several isolated groups of mountains rise abruptly from the prairie, bearing stands of conifers. A large number of conical or flat-topped buttes rise several hundred feet above the general land level, some of which bear scattered stands of deciduous or coniferous trees. Otherwise the area is treeless except for some growth along rivers and other water-courses.

SOILS[4]

The soils of the northern Great Plains fall in the Chestnut, Brown, and Lithosol and shallow soils groups. The Chestnut group is represented by the Williams, Morton, Bainville, and similar associated soils, which occupy most of the area in North Dakota,

[4] Descriptions of soils of the area are taken from standard published material *(19)*.

in northern South Dakota, in northern and extreme eastern Montana, and in eastern Wyoming. The Williams series has developed over calcareous glacial till and is characterized by surface soils of a dark grayish-brown color, ranging in depth from 6 to 10 inches. The upper subsoil is brown or light brown; the lower subsoil, beginning at a depth of about 18 inches, is grayish yellow or almost white, owing to its high content of lime. The Morton series is similar in appearance to the Williams but is underlain by sandstone or shales. The Bainville series is made up of thin soils developed over sandstone and shales on hilly areas.

The Brown soil group is represented by the Joplin series, which extends over most of the Plains section of Montana and northern Wyoming not occupied by the soil series in the Chestnut group. The Joplin series has developed from glacial drift in the northern part and from shales and sandstone in the central and southern parts of this section. The surface layer is grayish brown or gray to a depth of 7 to 10 inches. The subsoil is grayish brown or brown and is underlain at a depth of 12 to 16 inches by light-gray, very calcareous material. This in turn is underlain at 24 to 30 inches by the parent material. In southern Montana and eastern Wyoming, light-colored soils similar in profile to those of the Joplin series have developed from sandstone and shales.

The Lithosol and shallow soils group is represented by the Pierre series in central and western South Dakota and at the extreme eastern edge of Wyoming. This series, developed from calcareous shales, has moderately dark surface soils and dense clayey or shaly subsoils. It is extremely sticky and plastic when wet and is hard and tough when dry. Unaltered or partly weathered shale, the parent material, is usually within a depth of 3 feet on smooth areas and nearer the surface on exposed or eroded slopes. Lime may occur in the surface soil and is always abundant at a depth of 18 to 24 inches. In dry seasons the soil cracks badly and loses moisture rapidly. The soil cannot absorb moisture readily except through the cracks, and much of the precipitation is lost through runoff and evaporation.

Soils of the Barnes series prevail over a small area along the extreme eastern edge of the northern Great Plains area.

Climate[5]

The climate of the northern Great Plains is characterized by extremes of temperature in both winter and summer, a comparatively short growing season, low average rainfall, frequent drought periods, and strong drying winds. During the period 1914–46 the mean temperature averaged 44° F., with a range of 33° to 56°; maximum temperatures averaged 102°, with a range of 86° to 121°; and minimum temperatures averaged –30°, with a range of 0° to –60°. Temperatures recorded by one North Dakota cooperative weather station between February and July of the same year had a range of 171°. During the same 6-month

[5] The discussion of climate is based on U. S. Weather Bureau data *(20)*.

period, the temperatures recorded at two North Dakota stations less than 100 miles apart had a range of 181°.

Within the study period very severe frosts throughout the area occurred in late May, when plant growth was well advanced, and also in early September, before milder freezing temperatures had checked the current growth rate. The frost-free period averaged 129 days, ranging from 49 to 202 days. Killing frosts were recorded in each month of the year.

Annual precipitation within the area in the period 1914–46 averaged 14.85 inches, with a range of 3.54 to 39.89 inches. On an average approximately 76 percent of the annual rainfall, or 11.32 inches, came during the growing-season months, April–September. The growing-season rainfall ranged from 2.00 to 33.46 inches. Much of this rain fell in small amounts or in storms having high intensity. The effectiveness of small showers is slight, a large part of the moisture being lost at once by evaporation. Storms of high intensity contribute little to the water content of the soil except in depressions where runoff collects. Snow which fell before the growing season was very beneficial if it accumulated in drifts among the trees. Oftentimes in early spring the

FIGURE 2.—These snowdrifts in a Morton County, N. Dak., shelterbelt, in the spring of 1936, contained about 20 inches of water—5 inches more than the locality's normal annual precipitation and about 13.5 inches more than the total precipitation received locally in that year.

water yield of drifts a few feet deep was greater than the entire year's precipitation (fig. 2).

COOPERATIVE PROCEDURE

The plan of the cooperative demonstration shelterbelt program provided that the United States Department of Agriculture, under certain conditions, would furnish without charge to a limited number of dry-land farmers the planting stock necessary to plant one or more units of a farmstead shelterbelt. The units were to be located where they would offer wind and snow protection to farm buildings, orchards, gardens, livestock, or other farm necessities. Each farmer, before receiving trees, agreed to follow instructions furnished by the Department in selecting the planting site, preparing it, planting the trees, and caring for them.

A Department representative inspected each planting site to collect information on topography, soil type, land preparation, and size of area prepared for trees. A planting plan was prepared on the basis of this information, which showed the number of rows, arrangement of species, and distance between rows and between trees in the row. This plan was mailed to the cooperating farmer before the trees were shipped. It was accompanied by instructions on methods of storing the trees until planting time and on planting methods. Planting stock was shipped in the spring following acceptance of the planting site by the Department representative. A circular outlining methods for care and maintenance of shelterbelt trees was mailed to each cooperating farmer during the month of May following completion of the planting operation.

The instructions on care and maintenance recommended cultivating the shelterbelt area for control of grass and weed growth and to keep the soil in condition to absorb rainfall, as long as it was possible to work between the trees or until overhead shade became dense enough to retard foreign growth. Clean cultivation of a strip on all sides of the shelterbelt was recommended for the whole life of the belt, to keep out fire and sod. Mulching of trees was not recommended unless it became necessary for control of erosion caused by wind or water. Pruning was not recommended except to remove dead or injured limbs and to prevent multiple stems in trees of species for which a single stem is normal. Measures were recommended for control of insect and rodent pests.

Trees to replace any first-year losses were shipped in the second spring to all farmers who asked for them. In some instances replacement trees were furnished at a later time; ordinarily, however, replanting after the second year was not recommended, owing to the competition offered by the older trees.

PLANTING SITES

A great majority of the shelterbelts established in the cooperative project were so located as to shelter farm buildings from winds in either one or two directions. Many of these were de-

signed also to shelter orchards and gardens (fig. 3). Most of them were located north, west, or both north and west of the buildings, because over much of the northern Great Plains area prevailing winter winds are from the northwest. In the western parts of the area, where frequently the most damaging winds come from the southwest, some plantings were located south and west of the buildings. The side of a shelterbelt unit exposed to the prevailing wind is called the windward one and the other side the leeward one.

FIGURE 3.—This two-unit shelterbelt developed by a farmer in northern Wyoming protects buildings, orchard, and garden from damaging southwest winds.

Planting sites varied widely in topography and exposure. In some instances the fact that the trees had to be set close to existing buildings and to areas they were intended to protect meant planting on sites having heavy or highly alkaline soils, rolling topography, or other factors which might be unfavorable for successful survival and growth. Farm buildings are usually located on high land or on level land having good drainage. Consequently, only a small percentage of the plantings were made on low sites or on other sites receiving appreciable amounts of runoff water.

The soils of the planting sites used represent most of the soil types found in the area. They range from sand to clay, through many intermixtures. Unfavorable soil factors encountered include hardpan and slick spots. The latter contain alkaline salts in percentages so high as to stunt or kill trees and other vegetation. A well-defined zone of carbonate accumulation is found in many of the soils 1 to 3 feet below the surface.

PLANTING PLANS AND METHODS

Land Preparation

Most of the planting sites had been kept in clean summer fallow the year before the trees were planted. Occasional sites had been in grain that year or had recently been broken from sod; use of sites in such condition resulted usually from changes in farmers' plans between the time of site inspection and the time of planting. Most sites were well cultivated in preparation for planting.

Planting Stock

The planting stock supplied to farmers consisted of deciduous seedlings aged 1 or 2 years, according to species, and 2–1, 2–2, 3–1, and 3–2 conifer transplants[6] grown on the Mandan station under dry-land conditions from seed of known origin. In the course of the project some progress in obtaining higher establishment survivals[7] of conifers in years having only normal rainfall was made by undercutting nursery stock in the transplant field the year before digging it for shipment; transplanting seedlings into individual pots and growing them in the pots for 1 or 2 years; and coating tops with wax emulsions, either by dipping or by spraying, to reduce dehydration of the plants. Application of growth-regulating chemicals to tree roots was tested without producing any valuable results.

Width of Belt

The instructions furnished to farmers recommended that shelterbelts be made 100 to 200 feet wide where enough space was available. Actual widths, fitted to farm conditions and farm owners' desires, varied from 15 to about 200 feet. The number of rows per planting varied from 1 to 12 or more. Snow traps were included in some of the wider or more severely exposed plantings. After the middle thirties snow traps were seldom included, because it had become very evident that they worked too effectively in preventing drifting snow from passing through to the leeward rows of trees. It was recommended from that time on that new plantings be made no more than 8 to 10 rows wide except on sites severely exposed to northwest winds or located on south or east slopes where drainage from melting snow would be from windward toward leeward rows.

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[6] A 2–1 transplant, for example, is a tree which grew for two seasons in the nursery bed where it germinated, was then transplanted within the nursery, and grew there for one additional season.

[7] The phrases "establish survival" and "establishment survival" refer to survival through the first growing season following planting.

Tree and Shrub Species and Arrangement

Tree species used in the cooperative shelterbelt project during the first few years included, together with those native to the area, a number introduced from other parts of the United States and Canada. Some of these native and introduced species had been used by the Canadian Government for farm shelterbelts in the Prairie Provinces with good success. Willows and Carolina and Norway poplars made a poor showing in the first few years and were not used after 1919. Other species later proved generally unadapted to the climate of the northern Great Plains. Additional species, both native and introduced, were put to use when tests at the Mandan station yielded evidence that they had promise for the area.

The tree and shrub species planted in the cooperative project and the periods within which they were planted (not always continuously) are as follows:

	Period
Deciduous trees:	
Ash, green (*Fraxinus pennsylvanica* var. *lanceolata* (Borkh.) Sarg.)	1916–46
Boxelder (*Acer negundo* L.)	1916–46
Cottonwood, plains (*Populus sargentii* Dode)	1927
Elm, American (*Ulmus americana* L.)	1917–46
Elm, Siberian (Chinese) (*Ulmus pumila* L.)	1918–46
Hackberry (*Celtis occidentalis* L.)	1936–46
Honeylocust (*Gleditsia triacanthos* L.)	1935–41
Poplar, Carolina (*Populus canadensis* var. *eugenei* (Schelle) Rehd.)	1916–19
Poplar, Northwest (*Populus* sp.)	1922–34
Poplar, Norway (*Populus* sp.)	1916–19
Willow, laurel-leaf (*Salix pentandra* L.)	1916–19
Willow, Russian golden (*Salix fragilis* L.)	1916–19
Coniferous trees:	
Pine, jack (*Pinus banksiana* Lamb.)	1919–31
Pine, ponderosa (*Pinus ponderosa* Dougl.)	1919–46
Pine, red (*Pinus resinosa* Ait.)	1926–32
Pine, Scotch (*Pinus sylvestris* L.)	1919–36
Redcedar (*Juniperus virginiana* L. and *J. scopulorum* Sarg.)	1928–46
Spruce, Black Hills white (*Picea glauca* var. *densata* Bailey)	1921–36
Spruce, blue (*Picea pungens* Engelm.)	1922–46
Spruce, western white (*Picea glauca* var. *albertiana* (S. Brown) Sarg.)	1921–27
Deciduous shrubs:	
Buckthorn, Dahurian (*Rhamnus davurica* Pall.)	1935–46
Buffaloberry, silver (*Shepherdia argentea* (Pursh) Nutt.)	1920–35
Chokecherry, common (*Prunus virginiana* L.)	1921–46
Honeysuckle, Tatarian (*Lonicera tatarica* L.)	1939–46
Maple, Tatarian (*Acer tataricum* L.)	1920–25
Pea-tree, Siberian (*Caragana arborescens* Lam.)	1916–46
Plum, American (*Prunus americana* Marsh.)	1923–29
Russian-olive (*Elaeagnus angustifolia* L.)	1922–46

Many different combinations of species were used in the farm plantings. Each year, different row combinations were worked out from the stock on hand. From the early twenties onward, a shrub species of dense growth habit was always planted as the first windward row and was backed with trees of intermediate height; the tallest trees were placed in the approximate center of

the belt; and the rows from center to leeward followed a pattern similar to that of the windward half. Shrubs were usually planted in the outside leeward row of deciduous species, particularly prior to 1930. Belts thus composed show, after a few years, a more or less gradual slope from the windward and leeward outer rows to the center (fig. 4). In shelterbelts planted during the early years, conifers did not form a part of the original planting plan but were added later. From 1930 onward they were included in the original planting plan. Conifers were always placed in outer leeward rows regardless of their height characteristics; redcedar and spruce, on account of their dense habit of growth, were always placed in the outside row.

FIGURE 4.—Endwise view of a farm shelterbelt typical of those developed in the cooperative project.

The fact that spruces and cedars branch densely from ground level makes them very desirable for use in outside rows of plantings intended to hold wind and snow. With their all-year green foliage, also, conifers planted in leeward rows form a pleasing background for farm buildings. The aesthetic value of such a background on the Plains farm is considerable. Another reason for locating conifers in outside rows is the fact that they usually do not establish good survivals and it is desirable that any breaks in a shelterbelt be in the outer rows, where other use can be made of the vacant space, rather than in inner rows where competitive weeds would take over.

Spacing

For the first 4 years of the cooperative project, the trees were planted in a spacing approximating that used for many years by

the Canadian Government in planting shelterbelts in the Prairie Provinces. Later, several different spacings were used for rows and for trees within rows other than the first row to windward, in which the trees or shrubs were always set 3 or 4 feet apart. Spacing was varied from year to year or among periods of several years. It was not, as a general rule, varied among the plantings made in a given year; other factors varied so much from farm to farm that no reliable information could have been obtained in this way. The purpose of the variation was to find a spacing which would prevent excessive suppression both within and between rows; encourage crown development such as would prevent excessive growth of grass and weeds and excessive evaporation from trees and soil; and favor the survival, density, and height growth necessary for adequate protection from wind and snow. The spacings tested and the periods within which they were used are as follows:

Spacing (feet)[1]	*Period*	*Spacing (feet)*[1]	*Period*
4 by 8	1916–19	6 by 12	1927–30
6 by 6	1920–21	6 by 15	1931–39
6 by 8	1922	8 by 15	1940–42
6 by 10	1923–26		

[1] The first figure gives the distance between trees or shrubs in the row (except in the outside windward row, in which trees or shrubs were always spaced 3 or 4 feet apart), and the second figure gives the distance between rows.

MAKING AND SUMMARIZING RECORDS

So far as circumstances permitted, information was collected on land preparation the year prior to planting, first-season planting and survival, periodic growth and survival, winterkilling, and maintenance. Actual first-growing-season survival counts, by species, were reported at the end of each planting year by many of the cooperating farmers. Station representatives visited farms the summer before the trees were planted except during World War II, and visited the established plantings each growing season through the year 1922. Afterwards, plantings were inspected during the first, fifth, tenth, fifteenth, twentieth, twenty-fifth, and thirtieth growing seasons only. From the early thirties, data on winterkilling were taken in such a way that they could be summarized, percentages of trees being recorded under this injury classification: (1) None; (2) injury ranging from tip killing to killing back of not more than half the tree's height; (3) more severe killing back, including killing to the ground followed by sprouting from the base. From that time, also, data on diameter breast high and crown spread were taken. Diameter growth is less significant as a measure of the effectiveness of shelterbelt trees than crown-spread growth. Likewise percentage of trees killed back is less significant than percentage of trees remaining fairly free from winterkilling. Data on diameter growth and on percentages of trees killed back are therefore omitted from this report.

Plantings were "canceled" whenever, because of heavy losses or for some other reason, they ceased to be possible sources of useful data.

Only in occasional years was it possible to visit all the active plantings for collection of data. The average proportion of plantings on which data were collected at the respective 5-year age intervals varied from 72 percent at 5 years to 21 percent at 30 years. The low 30-year figure is due to World War II restrictions on the use of automobiles, which prevented any collection of data during the years 1942–45. On an average, the plantings visited at a given age interval amounted to 63 percent of the total then active.

Within the great expanse of the northern Great Plains, where normal moisture conditions are marginal for successful growth and survival of trees and shrubs, many factors might affect the success attained in growing shelterbelts. In order to discover any appreciable differences in growth and survival among different parts of the study area and determine the causes of any such differences, the area was divided into nine parts as indicated in figure 5 and growth and survival data were summarized accord-

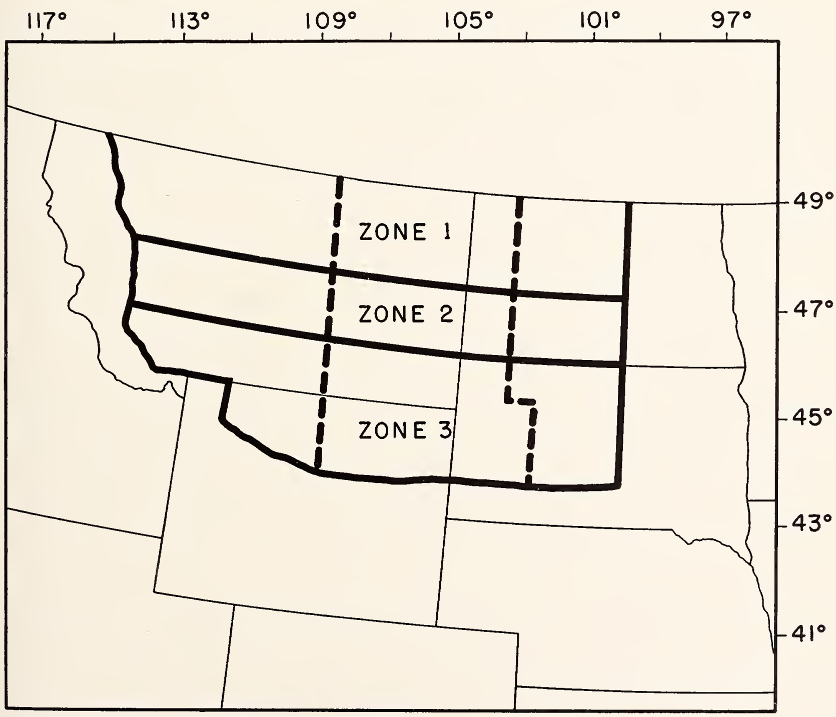

FIGURE 5.—North-south zones (marked off by heavy lines) and east-west zones (marked off by broken lines) into which the northern Great Plains area was divided for the purpose of studying influences on growth and survival.

ingly. The data were later summarized for the three north-south zones and the three east-west zones indicated in the figure.

REVIEW OF LITERATURE

Recommendations regarding tree species to be grown on the northern Great Plains and methods for growing them there have appeared from time to time in numerous publications by State, Federal, and other workers. Data covering only a few years of the early life of the trees have little value. Trees of some species gave excellent promise the first 5 years but passed out of existence before they reached the age of 10 years. To be relied upon, data must cover a period of such length that the trees are likely to have been subjected within it to nearly the full range of variation in each of the climatic factors governing their growth and survival.

Publications dealing with tree experiments carried out wholly or in part within the northern Great Plains area have been written by Wilson and Cobb *(23)*; Johnson and Cobb *(12)*; Harrington and Morgan *(10)*; Jensen and Harrington *(11)*; Scholz *(17)*; Towle *(18)*; Aune, Hurst, and Osenbrug *(1)*; Mathews and Clark *(15)*; George *(5, 6, 7, 8,* and *9)*; Wilson *(22)*; and Ware *(21)*.

Munns and Stoeckeler *(16)* report average height, survival, and crown spread for all species encountered in a survey of Prairie States Forestry Project shelterbelts scattered throughout the north-south extent of the Great Plains. The parts of North and South Dakota covered by their survey lie east of the Great Plains area shown in figure 1. The oldest plantings they observed were 10 years of age.

The functions of windbreaks in protecting farm buildings and crops have been discussed by Bates (*2*).

PLANTINGS MADE AND SHELTERBELTS GROWN

Table 1 shows the numbers of plantings made during the years 1916–42; the percentages of these plantings which were active at the ends of the fourth, fifth, tenth, fifteenth, twentieth, twenty-fifth, and thirtieth growing seasons; and the percentages of the active shelterbelts from which data were collected during individual growing seasons. Figure 6 shows graphically what percentages of the plantings remaining active at the end of each inspection period were considered effective as windbreaks and as snowbreaks, respectively.

As is shown in table 1, less than half the plantings of the period 1916–19 remained active after the first 5 years. This fact has two main reasons: (1) A large percentage of the planters were new homesteaders who knew little about the climate of the northern Great Plains or about tree growing; and (2) certain tree species (such as willows and Carolina and Norway poplars) and certain tree-growing methods were used which were not adapted to the climate. For the planting years from 1920 to about 1930, progress in finding hardier species and better methods of planting and

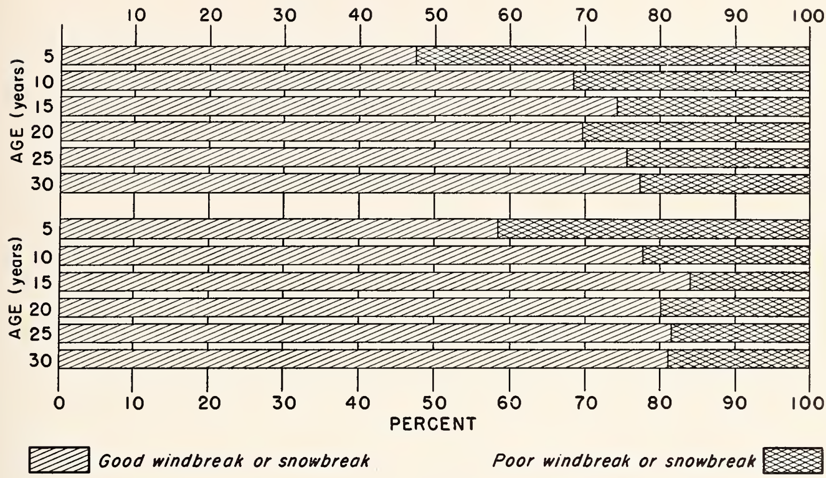

FIGURE 6.—Effectiveness of active plantings, as windbreaks (top) and as snowbreaks (bottom), after 5 to 30 years.

maintaining shelterbelts was reflected in a gradual decrease of cancellations at the end of the first 5 years. For the drought years 1931–36, the 5-year cancellation percentage increased so that for 1936 it was 47. Only 3 percent of the plantings of 1942, the next series for which a normal schedule of inspections was possible, were canceled at the end of 5 years. Cancellation at 10 years and later ages shows trends similar to those described for cancellation at 5 years.

For all planting years, the active shelterbelts averaged 78 percent at 5 years, 69 percent at 10 years, 66 percent at 15 years, 57 percent at 20 years, 41 percent at 25 years, and 32 percent at 30 years.

FIRST-YEAR SURVIVAL, BY SPECIES

First-year survival percentages for deciduous and coniferous species used in each of the planting years 1916–42 are shown in table 2. It will be noted that survivals of deciduous species were better than 72 percent except in the years 1919, 1934, and 1936, the second and third of which were very severe drought years throughout the northern Great Plains. Conifer survivals were high only for the planting years 1923, 1927, 1928, 1932, and 1940–42. In 1923 precipitation was approximately normal as to seasonal and annual totals and was well distributed through the growing-season months, April to September. In 1927, 1928, and 1932 precipitation was greater than normal and was very abundant during the months of May through August, which are those most critical for establishment of conifers. Precipitation in the years 1940–42 was generally above average throughout the area.

The data show that stock of selected deciduous species can readily become established under the normally dry conditions

TABLE 1.—*Cooperative shelterbelts planted in each of the years 1916–42, percentages of these shelterbelts active at the end of the fourth growing season, at the end of the fifth growing season, and at the end of each successive fifth growing season thereafter, and percentages of the active shelterbelts from which data were collected* [1]

Planting year	Shelter-belts planted	Active at end of fourth growing season	Fifth growing season		Tenth growing season		Fifteenth growing season		Twentieth growing season		Twenth-fifth growing season		Thirtieth growing season		Active at end of Study period	Average visited per 5-year interval
			Visited	Active at end	Visited	Active at end	Visited	Active at end	Visited	Active at end	Visited	Active at end	Visited	Active at end		
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1916	625	59	94	45	94	40	100	36	98	35	97	31	0	31	31	84
1917	228	51	100	45	99	39	30	39	79	36	99	34	74	33	33	81
1918	72	49	51	44	94	33	50	32	96	29	5	29			29	61
1919	200	58	77	55	98	48	21	47	22	47	0	47			47	46
1920	86	84	89	81	100	65	96	60	98	55	0	55			55	80
1921	91	96	93	87	100	74	90	69	100	63	0	63			63	80
1922	166	100	100	88	25	78	69	70	99	61	56	61			61	70
1923	221	100	99	80	74	77	96	73	0	73					73	70
1924	130	100	100	87	31	85	24	84	0	84					84	41
1925	177	100	100	91	99	90	98	85	0	85					85	76
1926	192	100	100	88	90	86	100	80	0	80					80	75
1927	199	99	42	98	66	91	97	86	65	85					85	67
1928	229	98	71	92	98	85	4	85							85	59
1929	202	99	23	97	27	92	0	92							92	17
1930	223	99	95	92	96	86	0	86							86	66
1931	254	99	86	83	94	71	0	71							71	65
1932	234	93	61	83	98	69	50	68							68	71
1933	154	97	97	79	5	79									79	56
1934	139	97	33	89	0	89									89	17
1935	53	100	100	70	0	70									70	59
1936	209	100	90	53	0	53									53	59
1937	0															
1938	150	100	3	100											100	3
1939	111	100	0	100											100	0
1940	114	100	0	100											100	0
1941	105	100	0	100											100	0
1942	106	100	71	97											97	71
Total or average	4,670	88	72	78	70	69	53	66	48	57	57	41	21	32	70	63

[1] Plantings made in 1916-21 were inspected in each of the first 4 growing seasons, and those made later were inspected in their first growing season. Further inspections were made in the fifth, tenth, fifteenth, twentieth, twenty-fifth, and thirtieth growing seasons. A difference in percentage of active plantings between the ends of the fourth and fifth growing seasons represents the number of cancellations resulting from inspections made in the fifth year, and such a difference between the ends of any two seasons separated by one 5-year interval represents the number of cancellations resulting from inspections made in the later season. A shelterbelt was canceled from the records if it was considered to have ceased, because of heavy losses or for some other reason, to be a possible source of useful data. Percentages of shelterbelts visited in the fifth growing season are based on the numbers active at the end of the fourth growing season, and percentages of shelterbelts visited in any other growing season are based on the numbers active 5 years earlier. All percentages have been rounded off to the nearest whole number.

found on the northern Great Plains if planted on land which was summer-fallowed the previous year. Conifer stock can become established satisfactorily only in years when growing-season precipitation is normal in quantity and well distributed or in years of abundant rainfall.

TABLE 2.—*Plantings of deciduous and coniferous species made in each of the years 1916–42, and percentages of the trees reported as surviving the first year*

Planting year	Deciduous species			Coniferous species		
	Plantings made	Plantings reported	Tree survival	Plantings made	Plantings reported	Tree survival
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*
1916	625	272	80.0	0		
1917	228	81	81.2	0		
1918	72	21	72.2	0		
1919	200	186	59.4	23	0	
1920	86	43	84.8	128	60	14.0
1921	91	38	86.1	112	46	34.2
1922	166	112	91.6	59	38	24.3
1923	221	199	86.2	74	66	62.8
1924	130	128	94.0	37	32	7.4
1925	177	172	88.7	0		
1926	192	189	87.1	36	31	25.8
1927	199	185	94.0	52	48	87.1
1928	229	208	82.1	44	39	59.8
1929	202	183	85.5	38	27	19.8
1930	223	205	86.4	51	39	23.3
1931	254	233	73.5	13	8	4.6
1932	234	198	94.8	31	18	62.2
1933	154	120	78.1	37	30	11.7
1934	139	117	58.6	21	13	10.3
1935	53	36	90.7	37	27	36.6
1936	209	127	22.9	23	15	2.4
1937	0					
1938	150	113	81.0	10	8	36.0
1939	111	85	82.4	33	19	38.5
1940	114	100	86.2	93	70	53.5
1941	105	83	93.4	93	76	81.4
1942	106	65	96.0	88	52	86.3

GROWTH AND SURVIVAL FOR STUDY PERIOD, BY SPECIES

When data on growth and survival of several of the more commonly planted species were summarized for each of the zones indicated in figure 5, fairly consistent differences were found between north-south zones but were not found between east-west zones. The latter finding is in contrast with that of Munns and Stoeckeler *(16)*, who noted distinct differences in shelterbelt tree growth rates as they proceeded westward in studying results of the Prairie States Forestry Project. In their study they sampled

TABLE 3.—*Average temperature means and extremes, first and last killing-frost dates, frost-free periods, and seasonal and annual precipitation for the years 1914–46 in the northern Great Plains shelterbelt area*[1]

North-south zone[2]	Temperature averages			Average killing-frost dates		Average annual frost-free period	Average precipitation	
	Annual mean	Annual maximum	Annual minimum	Last in spring	First in fall		April-September	Annual
	° *F.*	° *F.*	° *F.*			*Days*	*Inches*	*Inches*
1	42 (33–50)	100 (86–116)	−33 (0– −60)	5/17 (4/1–7/6)	9/21 (8/7–11/5)	127 (49–195)	10.62 (2.14–23.27)	13.62 (4.02–27.29)
2	44 (38–52)	102 (86–121)	−31 (−6– −53)	5/17 (4/5–7/2)	9/22 (8/7–11/5)	128 (64–202)	11.10 (2.00–23.85)	14.75 (3.54–31.16)
3	46 (34–56)	104 (90–119)	−26 (−5– −57)	5/12 (4/1–6/29)	9/28 (8/25–11/2)	139 (84–198)	12.24 (2.23–33.46)	16.16 (3.66–39.89)

[1] This table summarizes U. S. Weather Bureau data (*20*). It represents records taken at 75 stations operated by or maintained in cooperation with the Weather Bureau within the cooperative-shelterbelt-project area, including 33 in zone 1, 22 in zone 2, and 20 in zone 3. Periods represented by data from individual stations range from 11 to 33 years. Figures in parentheses under each average indicate the range of values averaged.

[2] Zone boundaries are shown in fig. 5.

that part of North Dakota lying east of zones 1 and 2, which had an average rainfall of approximately 18 inches, and the eastern two-thirds of the part of South Dakota lying east of zone 3, which had an average annual rainfall of approximately 21 inches. The average rainfall in these areas varied from east to west, that in the extreme east being several inches more than that in the extreme west. The decrease in average rainfall from east to west in the areas studied by Munns and Stoeckeler explains why they found distinct differences in tree growth rates as they proceeded westward. Similar rainfall variation from east to west was not found among the three east-west zones under discussion here.

Table 3 gives climatic data for the years 1914–46 for each of the north-south zones indicated in figure 5. The data show small progressive increases in mean and maximum temperatures, frost-free period, and seasonal and annual precipitation from zone 1 to zone 3. Lower minimum temperatures occur in the order from zone 3 to zone 1. The ranges of values averaged indicate that there are few, if any, appreciable climatic differences among the respective zones. Average annual precipitation in all zones was marginal for successful tree and shrub growth.

Table 4 presents growth, survival, and winterkilling data for the species of trees and shrubs used in the shelterbelt plantings. Zone averages are shown for the ages 5 years and 10 years and the most advanced ages for which reliable data are available, whether 15, 20, 25, or 30 years. Twenty tree and shrub species or species groups are compared graphically in figures 7 and 8 as to average height and survival at the age 10 years and at the most advanced ages for which reliable data are available. Generally, although not for all species, survival was somewhat poorer in zone 3 than in zones 1 and 2. Also, height growth of deciduous trees was somewhat less in zone 3. On the whole, any beneficial influences which might have accrued in zone 3 from higher temperatures, longer growing season, and higher seasonal and annual precipitation were more than offset by the influences of the heavier soils found over much of that zone, a somewhat higher evaporation rate during the growing season, and possibly other adverse factors. These heavy soils absorb water very slowly and release a much lower percentage of their held moisture for plant use than do the lighter soils found in other parts of zone 3 and in zones 1 and 2. Trees and shrubs growing on the heavy soils were frequently weakened by the lack of available water to such an extent that they became highly subject to severe injury by insects and to partial or complete killing back during the winter months.

None of the shrub species attained an average height of 12 feet, and none of the trees but poplars, Siberian elm, jack pine, and Scotch pine attained one of approximately 20 feet. All deciduous species for which 20- to 30-year data are available made more growth during the first 10 years than they did during the following 10 to 20 years. The average heights of cottonwood, silver buffaloberry, and American plum at 20, 25, and 15 years, respectively, were lower than those at 10 years. Killing back of terminal growth is largely responsible for the fact that average

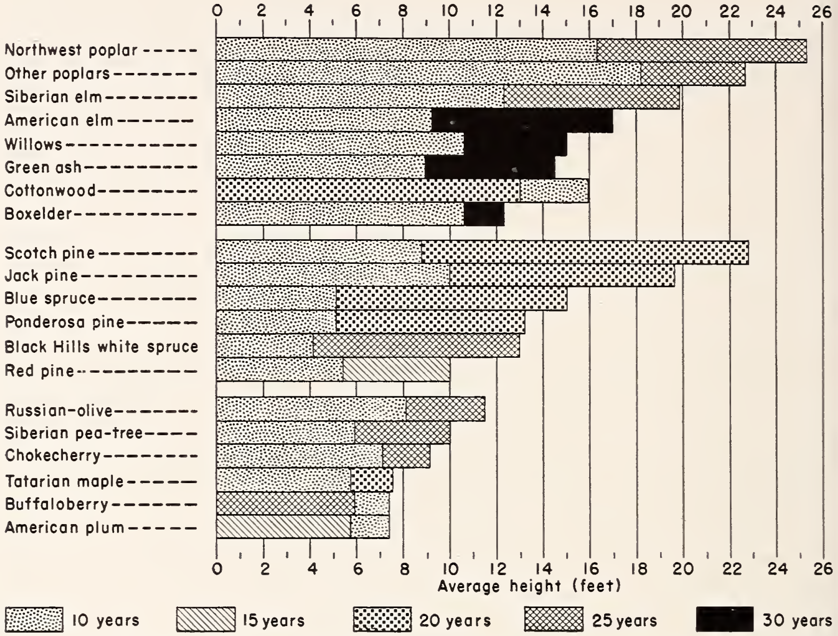

FIGURE 7.—Average heights of 20 tree and shrub species or species groups used in cooperative farm shelterbelts, at 10 years and at the most advanced ages for which reliable data are available.

heights of deciduous species increased more slowly or diminished after 10 years. Conifers generally made as much growth in the second 10-year period as in the first, or still more. Conifers were not killed back to such a degree as deciduous species.

Survivals of shrub species other than Siberian pea-tree and chokecherry for which 10-year and 20- or 25-year data are available dropped sharply between those ages. American plum survival was reduced by approximately 55 percent between the tenth and the fifteenth year. Survivals of silver buffaloberry and Tatarian maple at the 25-year and 20-year points, respectively, were so low that these shrubs cannot be considered suitable for planting on the northern Great Plains.

Survivals of green ash, boxelder, and elms between the ages 10 and 25 or 30 years were fairly good. Those of poplar, willow, and cottonwood species became too low to justify further planting of these species under dry-land conditions on the northern Great Plains.

Of the conifers which became established, blue spruce alone was found to maintain good survivals for 15 to 20 years. Black Hills white spruce survived fairly well for the first 10 years but suffered heavy losses during the next 15 years. Ponderosa pine suffered a heavy loss between the fifth and tenth years but only a small loss between the ages 10 and 20 years. It is the most

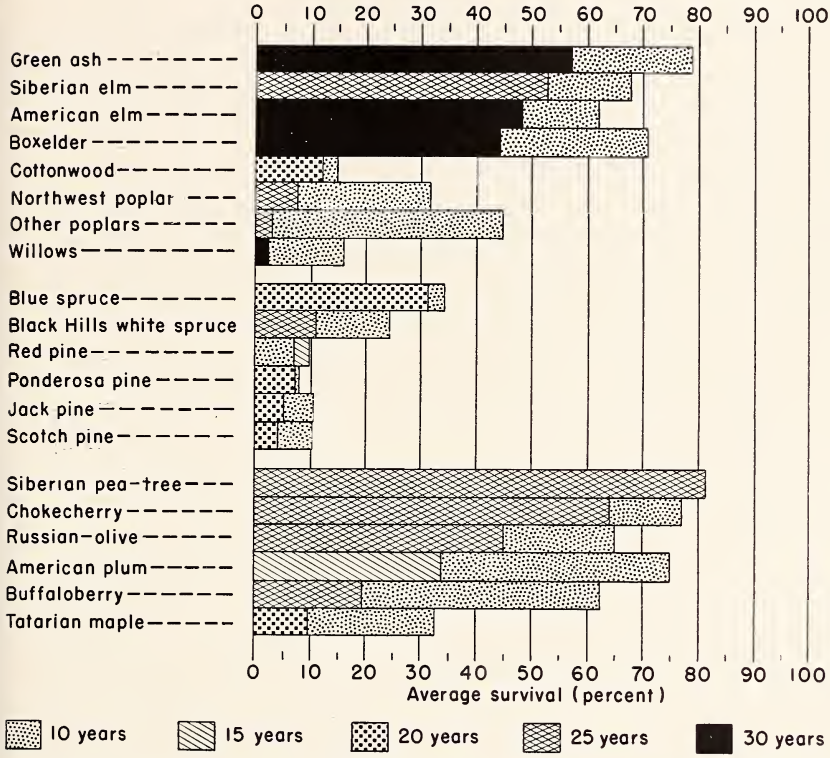

FIGURE 8.—Average survivals of 20 tree and shrub species or species groups used in cooperative farm shelterbelts, at 10 years and at the most advanced ages for which reliable data are available. (Survival of Siberian pea-tree at 10 years averaged the same as its survival at 25 years.)

hardy of the pine and spruce species tested and grows naturally on very dry buttes and ridges in western North and South Dakota and on very dry sites in central and southeastern Montana and northeastern Wyoming. Red pine also suffered a heavy loss between the fifth and tenth years, but its survival was higher at 15 than at 10 years. Redcedars are omitted from figures 7 and 8 because data for them, aside from a single planting, are limited to a 10-year period. Observations made on *Juniperus scopulorum* growing naturally on very dry, poor sites throughout the western two-thirds of the region and on *J. virginiana* growing naturally on somewhat better sites in the extreme eastern part of the region indicate that both species are capable of surviving for long periods even under difficult growing conditions.

Deciduous Trees

Green ash made good growth progress throughout the study period. Survival decreased slightly each 5-year period but con-

TABLE 4.—*Average height and crown spread, freedom from winterkilling, and survival of trees and shrubs in shelterbelts 5, 10, and 15 to 30 years after planting, by species and zone*[1]

Species and zone	Height, by age of plantings						Crown spread, by age of plantings						Freedom from winterkilling, by age of plantings						Survival, by age of plantings					
	5 years		10 years		15 to 30 years		5 years		10 years		15 to 30 years		5 years		10 years		15 to 30 years		5 years		10 years		15 to 30 years	
	Number	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Deciduous trees:																								
Green ash:																								
1	935	5.2	801	9.3	40	[2]14.9	183	2.7	297	5.7	40	[2]7.9	249	91	346	87	40	[2]76	794	87.9	757	81.4	40	[2]59.5
2	546	5.4	481	8.9	19	[2]14.6	96	2.2	206	5.4	19	[2]7.9	138	85	251	83	19	[2]67	473	88.7	467	79.4	19	3
3	384	5.5	346	7.7	4	[2]9.3	46	4.4	161	4.8	4	[2]5.3	50	82	164	79	4	[2]63	342	87.4	343	70.8	5	[2]28.0
Total or average	1,865	5.3	1,628	8.9	63	[2]14.5	325	2.8	664	5.4	63	[2]7.7	437	88	761	84	63	[2]72	1,609	88.0	1,567	78.5	64	[2]57.3
Boxelder:																								
1	837	7.7	809	11.3	27	[2]12.1	48	3.9	268	8.8	27	[2]10.8	138	84	337	68	27	[2]59	620	90.4	691	78.0	29	[2]52.2
2	500	7.4	477	10.7	14	[2]12.9	34	5.8	192	8.6	14	[2]10.6	93	79	230	70	14	[2]60	395	90.2	437	72.7	14	[2]32.9
3	378	7.6	326	9.0	3	[2]11.7	19	3.7	150	7.7	3	[2]11.0	32	76	157	59	3	[2]60	327	83.8	332	56.3	4	[2]26.3
Total or average	1,715	7.6	1,612	10.6	44	[2]12.3	101	4.5	610	8.5	44	[2]10.8	263	81	724	67	44	[2]59	1,342	89.0	1,460	71.0	47	[2]44.0
Plains cottonwood:																								
1	11	11.3	11	14.7	11	[3]27.5					11	[3]14.3					11	[3]87	13	66.2	26	11.7	22	[3]10.0
2	19	11.1	6	18.0	8	[3]24.5					8	[3]12.8					8	[3]90	19	91.1	10	27.0	12	[3]16.3
3			2	16.0	34	[3]5.7															9	10.6		
Total or average	30	11.1	19	15.9	53	[3]13.0					19	[3]13.6					19	[3]89	32	81.0	45	15.0	34	[3]12.0
American elm:																								
1	107	4.5	52	8.5	30	[2]17.8	53	2.9	15	4.5	29	[2]10.2	54	87	15	60	30	[2]78	76	62.4	24	44.2	34	[2]48.5
2	65	4.7	32	9.6	15	[2]15.8	35	2.6	6	5.0	15	[2]9.4	35	81	6	78	15	[2]76	57	69.6	21	81.7	15	[2]53.3
3	34	5.7	5	13.6	5	[2]15.6	15	3.1			5	[2]9.4	15	54			5	[2]78	17	58.8			5	[2]29.0
Total or average	206	4.7	89	9.2	50	[2]17.0	103	2.8	21	4.6	49	[2]9.9	104	80	21	65	50	277	150	65.0	45	62.0	54	[2]48.0
Siberian elm:																								
1	264	6.4	150	12.9	3	[4]10.7	115	4.1	128	10.5	3	[4]7.3	129	84	131	83	3	[4]70	279	69.6	157	65.6	3	[4]30.0
2	210	7.7	139	11.5	4	[4]26.5	81	5.0	122	10.7	4	[4]17.0	94	80	124	89	4	[4]83	230	74.3	144	72.6	4	[4]77.5
3	133	7.7	98	12.3	2	[4]20.5	40	4.7	93	9.9	2	[4]14.0	40	86	93	85	2	[4]55	144	73.7	105	62.6	2	[4]37.5
Total or average	607	7.2	387	12.3	9	[4]19.9	236	4.5	343	10.4	9	[4]13.1	263	83	348	86	9	[4]72	653	72.2	406	67.6	9	[4]52.8

See footnotes at end of table, p. 26.

Deciduous trees—Con.:																								
Hackberry:																								
1	13	2.7	-----	-----	-----	-----	13	2.2	-----	-----	-----	-----	13	85	-----	-----	-----	-----	17	50.3	-----	-----	-----	-----
2	18	3.3	-----	-----	-----	-----	18	2.2	-----	-----	-----	-----	18	72	-----	-----	-----	-----	22	54.5	-----	-----	-----	-----
3	6	4.2	-----	-----	-----	-----	6	2.8	-----	-----	-----	-----	6	70	-----	-----	-----	-----	7	60.7	-----	-----	-----	-----
Total or average	37	3.2	-----	-----	-----	-----	37	2.3	-----	-----	-----	-----	37	76	-----	-----	-----	-----	46	53.9	-----	-----	-----	-----
Honeylocust:																								
1	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
2	2	2.0	-----	-----	-----	-----	2	1.5	-----	-----	-----	-----	2	100	-----	-----	-----	-----	2	52.5	-----	-----	-----	-----
3	8	3.3	-----	-----	-----	-----	8	2.6	-----	-----	-----	-----	8	66	-----	-----	-----	-----	9	52.2	-----	-----	-----	-----
Total or average	10	3.0	-----	-----	-----	-----	10	2.4	-----	-----	-----	-----	10	73	-----	-----	-----	-----	11	52.3	-----	-----	-----	-----
Northwest poplar:																								
1	478	10.2	358	16.6	25	[4]26.2	22	4.7	118	10.9	25	[4]14.0	46	88	164	78	25	[4]85	408	84.2	459	38.9	38	[4]13.8
2	266	9.5	187	16.2	9	[4]21.3	14	3.3	68	9.6	9	[4]12.3	24	73	101	68	9	[4]73	233	79.6	265	36.4	29	[4]1.6
3	237	9.4	101	15.4	3	[4]29.0	9	4.7	41	8.9	3	[4]16.0	14	84	46	67	3	[4]100	228	74.1	234	16.1	12	[4]1.7
Total or average	981	9.8	646	16.3	37	[4]25.3	45	4.2	227	10.2	37	[4]13.8	84	83	311	73	67	[4]83	869	80.3	958	32.6	79	[4]7.5
Other poplars:																								
1	120	7.8	61	16.9	21	[4]20.7	-----	-----	-----	-----	21	[4]10.6	-----	-----	-----	-----	14	[4]84	4	70.0	34	34.7	77	[4]3.1
2	47	9.4	34	20.1	8	[4]26.8	-----	-----	-----	-----	8	[4]14.8	-----	-----	-----	-----	8	[4]54	1	100	16	48.1	31	[4]3.5
3	20	12.7	19	18.9	3	[4]28.7	-----	-----	-----	-----	3	[4]14.0	-----	-----	-----	-----	3	[4]37	1	100	9	76.7	16	[4]1.6
Total or average	187	8.7	114	18.2	32	[4]22.7	-----	-----	-----	-----	32	[4]12.0	-----	-----	-----	-----	25	[4]69	6	80.0	59	44.7	124	[4]3.0
Willows:																								
1	157	4.7	104	10.6	11	[2]14.5	-----	-----	-----	-----	11	[2]11.8	-----	-----	-----	-----	54	[2]76	2	50.0	53	22.5	38	[2]2.2
2	69	4.8	42	11.2	4	[2]17.0	-----	-----	-----	-----	4	[2]12.3	-----	-----	-----	-----	14	[2]34	4	17.5	37	10.4	11	[2]1.8
3	41	6.2	29	10.0	2	[2]14.0	-----	-----	-----	-----	2	[2]9.0	-----	-----	-----	-----	5	[2]20	-----	-----	17	9.1	4	[2]2.5
Total or average	267	5.0	175	10.6	17	[2]15.0	-----	-----	-----	-----	17	[2]11.6	-----	-----	-----	-----	73	[2]64	6	28.3	107	16.2	53	[2]2.2
Coniferous trees:																								
Jack pine:																								
1	5	4.6	13	9.7	4	[3]19.0	-----	-----	5	8.2	4	[3]13.8	-----	-----	2	100	4	[3]100	16	16.9	33	11.2	32	[3]2.7
2	3	4.3	6	10.7	3	[3]20.3	-----	-----	1	12.0	3	[3]8.0	1	100	2	100	3	[3]100	19	8.9	29	10.0	5	[3]23.0
3	3	7.3	4	9.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	7	7.9	10	8.0	-----	-----
Total or average	11	5.3	23	10.0	7	[3]19.6	-----	-----	6	8.8	7	[3]11.3	1	100	4	100	7	[3]100	42	11.8	72	10.3	37	[3]5.4
Ponderosa pine:																								
1	9	2.4	12	4.6	7	[3]13.3	3	2.3	4	3.0	7	[3]8.0	5	100	5	100	7	[3]99	28	16.7	19	5.9	26	[3]6.5
2	6	2.3	5	4.8	3	[3]12.0	5	1.0	2	3.0	3	[3]6.3	5	100	3	90	3	[3]100	22	15.7	19	7.6	11	[3]4.1
3	3	1.3	1	12.0	1	[3]16.0	1	1.0	-----	-----	1	[3]10.0	2	100	-----	-----	1	[3]90	8	8.1	2	25.0	1	[3]30.0
Total or average	18	2.2	18	5.1	11	[3]13.2	9	1.4	6	3.0	11	[3]7.7	12	100	8	96	11	[3]98	58	15.1	40	7.7	38	[3]6.4

TABLE 4.—*Average height and crown spread, freedom from winterkilling, and survival of trees and shrubs in shelterbelts 5, 10, and 15 to 30 years after planting, by species and zone*[1]—*Continued*

Species and zone	Height, by age of plantings						Crown spread, by age of plantings						Freedom from winterkilling, by age of plantings						Survival, by age of plantings					
	5 years		10 years		15 to 30 years		5 years		10 years		15 to 30 years		5 years		10 years		15 to 30 years		5 years		10 years		15 to 30 years	
	Number	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Coniferous trees—Con:																								
Red pine:																								
1	3	2.7	4	4.8	2	[5]8.0	-----	-----	2	4.0	2	[5]5.5	-----	-----	2	50	2	[5]100	19	15.8	14	12.1	4	[5]13.8
2	5	3.0	3	6.3	1	[5]14.0	-----	-----	2	3.5	1	[5]6.0	-----	-----	2	100	1	[5]100	14	20.4	12	1.7	2	[5]2.5
3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Total or average	8	2.9	7	5.4	3	[5]10.0	-----	-----	4	3.8	3	[5]5.7	-----	-----	4	75	3	[5]100	33	17.7	26	7.3	6	[5]10.0
Scotch pine:																								
1	9	3.8	12	9.6	3	[3]18.7	-----	-----	6	5.3	3	[3]10.7	-----	-----	7	100	3	[3]100	46	12.9	44	12.0	28	[3]1.8
2	3	3.7	8	7.6	1	[3]35.0	-----	-----	1	2.0	1	[3]6.0	-----	-----	1	100	1	[3]100	24	12.3	37	10.0	2	[3]35.0
3	2	2.0	1	9.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	12	9.2	8	.6	-----	-----
Total or average	14	3.5	21	8.8	4	[3]22.8	-----	-----	7	4.9	4	[3]9.5	-----	-----	8	100	4	[3]100	82	12.2	89	10.2	30	[3]4.0
Redcedar:																								
1	27	1.6	1	5.0	-----	-----	25	1.2	1	6.0	-----	-----	24	100	1	100	-----	-----	35	47.7	1	95.0	-----	-----
2	28	2.2	3	3.7	-----	-----	25	2.5	3	8.0	-----	-----	21	91	3	100	-----	-----	36	51.7	3	41.7	-----	-----
3	5	2.0	1	4.0	-----	-----	4	2.8	1	2.0	-----	-----	4	100	1	100	-----	-----	6	49.2	1	25.0	-----	-----
Total or average	60	1.9	5	4.0	-----	-----	54	2.0	5	6.4	-----	-----	52	97	5	100	-----	-----	77	49.7	5	49.0	-----	-----
Black Hills white spruce:																								
1	40	2.1	43	4.5	2	[4]13.0	4	1.0	13	3.5	2	[4]6.5	10	100	17	100	2	[4]100	76	36.6	77	30.7	3	[4]15.0
2	23	2.0	27	3.4	1	[4]16.0	-----	-----	8	2.8	1	[4]9.0	3	100	10	100	1	[4]100	52	40.5	57	20.8	4	[4]12.5
3	7	2.3	5	4.2	1	[4]10.0	1	1.0	2	2.0	1	[4]5.0	2	100	2	25	1	[4]100	18	24.7	14	7.7	2	[4]2.5
Total or average	70	2.1	75	4.1	4	[4]13.0	5	1.0	23	3.1	4	[4]6.8	15	100	29	95	4	[4]100	146	36.5	148	21.7	9	[4]11.1
Blue spruce:																								
1	14	2.2	14	5.0	1	[3]18.0	2	1.5	6	3.8	1	[3]10.0	6	100	8	100	1	[3]100	28	39.3	19	42.3	2	[3]15.0
2	18	3.2	16	5.3	3	[3]14.0	6	2.5	11	3.5	3	[3]8.3	11	100	12	100	3	[3]100	31	37.8	27	34.1	5	[3]38.0
3	4	2.0	2	5.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	12	15.4	6	13.3	-----	-----
Total or average	36	2.7	32	5.1	4	[3]15.0	8	2.3	17	3.6	4	[3]8.8	17	100	20	100	4	[3]100	74	34.7	52	34.7	7	[3]31.4

Coniferous trees—Con.:																								
Western white spruce:																								
1	3	1.7	2	4.5									1	100	2	100			3	91.7	4	25.0		
2	4	2.3	3	4.0					1	3.0			3	100					6	76.7	6	24.2		
3																								
Total or average	7	2.0	5	4.2					1	3.0			4	100	2	100			9	81.7	10	24.5		
Deciduous shrubs:																								
Dahurian buckthorn:																								
1	7	2.7					7	2.4					7	86					8	68.8				
2	8	3.9					8	3.6					8	88					8	66.9				
3																								
Total or average	15	3.3					15	3.1					15	87					16	67.9				
Silver buffaloberry:																								
1	10	4.4	11	7.2	6	[4]4.7	4	2.5	1	8.0	6	[4]3.5	4	100	1	100	6	[4]78	5	20.0	10	62.0	8	[4]21.3
2	15	4.9	13	7.5	4	[4]7.5	3	5.3	1	7.0	4	[4]6.3	3	100	1	100	4	[4]85	11	49.5	14	62.5	5	[4]27.0
3	7	5.3	3	8.0	4	[4]6.3	2	3.5			4	[4]5.3	2	100			4	[4]95	2	52.5	4	62.5	4	[4]8.8
Total or average	32	4.8	27	7.4	14	[4]5.9	9	3.7	2	7.5	14	[4]4.8	9	100	2	100	14	[4]84	18	41.7	28	62.4	17	[4]20.0
Common chokecherry:																								
1	64	4.1	53	7.4	6	[4]6.8	30	2.1	25	6.0	6	[4]6.7	31	87	27	82	6	[4]78	59	75.1	58	73.9	6	[4]64.1
2	52	4.7	43	7.4	8	[4]10.5	21	2.6	18	6.1	8	[4]8.8	23	89	21	75	8	[4]98	49	79.1	44	83.0	9	[4]66.1
3	35	3.8	22	5.9	1	[4]12.0	18	2.1	12	6.0	1	[4]12.0	18	86	13	75	1	[4]100	36	64.6	23	73.3	1	[4]50.0
Total or average	151	4.2	118	7.1	15	[4]9.1	69	2.2	55	6.0	15	[4]8.1	72	88	61	78	15	[4]90	144	74.0	125	77.0	16	[4]64.0
Tatarian honeysuckle:																								
1	3	2.7					3	2.3					3	100					3	91.7				
2	2	3.5					2	2.0					2	100					2	17.5				
3																								
Total or average	5	3.0					5	2.2					5	100					5	62.0				
Tatarian maple:																								
1	53	5.5	44	5.5	4	[3]6.8					4	[3]4.8			29	53	4	[3]62	52	72.2	52	38.1	11	[3]10.5
2	19	5.3	12	6.6	1	[3]12.0					1	[3]5.0			5	80	1	[3]100	21	71.7	21	30.7	1	[3]5.0
3	13	4.8	10	5.3	1	[3]6.0					1	[3]10.0			2	100	1	[3]100	15	52.0	18	19.2	1	[3]10.0
Total or average	85	5.4	66	5.7	6	[3]7.5					6	[3]5.7			36	60	6	[3]75	88	69.0	91	33.0	13	[3]10.0
Siberian pea-tree:																								
1	825	4.0	721	6.5	96	[4]10.2	155	1.8	317	4.6	96	[4]8.3	239	97	356	96	96	[4]95	759	87.6	672	89.5	98	[4]83.7
2	488	3.7	427	5.4	50	[4]9.9	75	1.6	227	3.9	50	[4]8.7	132	89	254	87	49	[4]91	467	82.0	413	76.5	52	[4]81.3
3	348	3.9	311	5.2	16	[4]8.8	54	3.9	169	4.2	16	[4]9.3	57	92	173	88	16	[4]81	341	77.8	321	69.8	18	[4]63.3
Total or average	1,661	3.9	1,459	5.9	162	[4]10.0	284	2.1	713	4.3	162	[4]8.5	428	94	783	91	161	[4]92	1,567	84.0	1,406	81.0	168	[4]81.0

TABLE 4.—*Average height and crown spread, freedom from winterkilling, and survival of trees and shrubs in shelterbelts 5, 10, and 15 to 30 years after planting, by species and zone*[1]*—Continued*

Species and zone	Height, by age of plantings						Crown spread, by age of plantings						Freedom from winterkilling, by age of plantings						Survival, by age of plantings					
	5 years		10 years		15 to 30 years		5 years		10 years		15 to 30 years		5 years		10 years		15 to 30 years		5 years		10 years		15 to 30 years	
	Number	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Feet*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Deciduous shrubs—Con.:																								
American plum:																								
1	21	4.6	24	7.3	21	[5]5.2	----	----	----	----	20	[5]3.4	2	100	19	49	20	[5]42	7	95.7	24	76.5	24	[5]39.6
2	17	5.2	19	7.4	12	[5]6.2	1	5.0	----	----	11	[5]4.3	3	100	16	77	12	[5]46	13	95.4	19	70.3	19	[5]23.9
3	6	6.2	2	9.0	2	[5]7.5	----	----	----	----	2	[5]4.5	----	----	----	----	2	[5]100	7	82.9	2	95.0	1	[5]42.5
Total or average	44	5.0	45	7.4	35	[5]5.7	1	5.0	----	----	33	[5]3.7	5	100	35	62	34	[5]47	27	92.0	45	75.0	47	[5]34.0
Russian-olive:																								
1	543	5.4	415	8.4	23	[4]10.9	151	3.4	242	7.2	23	[4]8.7	95	81	279	83	23	[4]75	546	70.9	456	66.0	25	[4]45.8
2	355	5.7	310	8.5	23	[4]11.7	81	3.7	199	7.2	23	[4]9.6	141	82	228	79	23	[4]70	359	76.7	333	68.4	25	[4]48.2
3	251	5.6	211	6.6	10	[4]12.2	49	5.5	151	6.2	10	[4]11.5	57	82	158	58	----	----	247	77.8	242	58.3	11	[4]35.5
Total or average	1,149	5.5	936	8.1	56	[4]11.5	281	3.8	592	6.9	56	[4]9.5	293	82	665	76	46	[4]73	1,152	74.0	1,031	65.0	61	[4]45.0

[1] Data on height and survival are for the period 1916–46; data on crown spread and freedom from winterkilling are for a period extending from the early thirties through 1946. Number indicates total of plantings visited. Percentages for freedom from winterkilling and for survival represent proportions of trees or shrubs within plantings. In terms of the total of plantings active at a given age, those inspected at that age averaged 63 percent for the project as a whole but for some years amounted to less than 25 percent (table 1). The plantings of a given species inspected at a given age o ten differed greatly in number from those inspected at an earlier age and very often included plantings which had not been inspected at the earlier age. These facts largely explain why, for example, average height for Siberian elm in zone 1, shown as 12.9 feet at 10 years, is shown as only 10.7 feet at 25 years. Another factor contributing to such differences is actual decadence of trees and shrubs of some species at the most advanced ages at which data were taken.

[2] Data for age 30 years.

[3] Data for age 20 years.

[4] Data for age 25 years.

[5] Data for age 15 years.

sistently averaged high. There is evidence that winterkilling of this tree increases slightly with age. Heavy infestations of the carpenterworm *(Prionoxystus robiniae)* and the ash borer *(Podosesia syringae fraxini)* resulted in severe killing back of tops, and in many plantings these insects tunneled the trunks so badly that the trees broke down at ground level or died out entirely. This kind of injury was more pronounced in South Dakota than in the other States and shares responsibility equally with soil type for the poorer showing made in zone 3. No practical control measures for large-scale application have been worked out which will prevent injury to green ash by boring insects. Green ash is subject also to injury by late-spring frosts. Although among the better of the taller-growing shelterbelt trees, green ash occasionally died out entirely where few or no losses were found in other species. Only infrequently was it broken down by drifted snow. It is suitable for planting in interior rows of either the windward or the leeward half of a shelterbelt.

Boxelder reached its peak of growth at about 15 years of age, when the trees averaged 12.6 feet in height. Winterkilling more than offset height growth in later years (fig. 9). Survivals dropped rapidly beyond the age 10 years. Growth and survival were poorest in zone 3. In widely spaced plantings this species usually develops into a multiple-stemmed tree with heavy, spreading side branches. Drifted snow frequently causes severe breakage of its limbs and stems. The species is highly subject to killing back on dry sites and may never attain more than a shrubby type

FIGURE 9.—Boxelder (right center) winterkilled to the ground in a shelterbelt planting in zone 3. Other species present are Northwest poplar (left center), which became a complete loss; green ash (to right of boxelder), heavily killed back in part of the row; Siberian pea-tree (outside right), similarly killed back; and Siberian elm (left), which showed no injury.

of growth. Its dense-growing habit, resulting from suckering from the root collar, makes it suitable for planting toward the windward side of a belt. Its use should be confined to the more moist sites.

Plains cottonwood was planted only in 1927. Growth began to decline after 10 years and survivals dropped rapidly after 5 years, averaging very low at 15 and 20 years. Winterkilling was not severe. The species is subject to leaf rust and other fungus infection. (Strains resistant to leaf rust infection are being developed by the South Dakota Agricultural Experiment Station.) Survival was confined to those plantings receiving supplemental moisture. This tree can be recommended only for the wetter sites and for rows at or near the center of the belt.

American elm made good growth progress, but its survivals dropped rapidly after 15 years. The best survival of this tree at 30 years was found in zone 2 and the poorest in zone 3. Height at 30 years was best in zone 1 and did not differ between zone 2 and zone 3. During the drought years heavy injury was caused by bark beetles, which girdled limbs and stems by tunneling around them immediately under the bark. In general the species gave better satisfaction on the lighter soils found in zones 1 and 2. It is recommended for planting in the center rows of a belt.

Siberian elm (commonly called Chinese elm) reached its maximum growth in zones 1 and 3 at about 20 years of age, when the average heights were 16.2 and 22.5 feet, respectively. Average height in zone 2 continued to increase through the twenty-fifth year. Survivals of more than 50 percent were present in all zones at 20 years, but these had suffered sharp reductions in zones 1 and 3 at 25 years. Winterkilling of varying degree was sometimes found in lateral branches when no killing back of tops had taken place. This tree grows rapidly and recovers rapidly from injuries of most kinds. It frequently outgrows and overtops other trees planted in adjacent rows. Siberian elm when young is highly subject to injury by jack rabbits. It is subject also to borer infestation and fungus infection. The wood is very brittle; trunks or large branches are frequently broken by gusty winds. This tree has an indeterminate habit of growth and seldom sets its terminal buds or drops its leaves before severe freezing temperatures occur in the fall. Methods have been recommended by the author *(8)* for hastening fall maturity of the species in order to reduce the possibility of severe winterkilling. Siberian elm should not be planted on low, wet sites. It is recommended for planting in the center rows of a shelterbelt. Results with this species were about the same in one zone as in another up to the age 15 years but were better in zones 2 and 3, in that order, than in zone 1 at the age 25 years.

Hackberry data are very limited. Heavy losses and considerable winterkilling occurred in the first 5 years. This tree does not become established so readily as some of the other deciduous species tested. Its indeterminate habit of growth makes it highly susceptible to early-fall freezes, and not infrequently it is killed back

severely by late-spring frosts. The species is native in the eastern part of zone 1 and farther south. It responded less well in zone 1 than in the two other zones. On the more moist sites, hackberry is recommended for planting in the second or third row of either the windward or the leeward half.

Honeylocust data are limited. Heavy losses (fig. 10) and injury occurred in the first 5 years. The tree's indeterminate habit of growth makes it very susceptible to early-fall freezes, terminal-growth killing frequently being evident in late October. The species cannot be recommended for planting elsewhere than in the southern part of zone 3.

FIGURE 10.—*A*, Honeylocust planting in western South Dakota killed by drought, insects, and neglect; *B*, a planting of the same species, about 30 miles distant, which shows no injury.

Northwest poplar, a hybrid generally considered superior to the native cottonwood, showed growth progress at each period, but its survival dropped rapidly after the first 5 years. Considerable winterkilling was present at all periods. Growth did not differ much among zones. Survival was best in zone 1. Survivals were confined to depressions and other sites receiving runoff moisture. This tree is an excellent choice for such sites. It is subject to borer infestation and to fungus infection.

The Carolina and Norway poplars became mixed in the shelterbelts as a result of replanting of fail spots and planting of additional rows. Their survivals dropped rapidly after 5 years and became very low between the ages 10 and 15 years. Winterkilling data are limited and variable. Survivals were confined to plantings on sites which received runoff moisture. (The early settlers used these poplars almost exclusively for their shelterbelt and tree-claim plantings.)

The Russian golden and laurel-leaf willows made variable growth and suffered heavy losses. Willows survived only in depressions and on other sites receiving supplemental moisture.

Coniferous Trees[8]

Jack pine made good growth progress but did not survive well. Of the trees which became established, about 50 percent died between the ages of 10 and 15 years. Losses were very heavy during the drought years of the middle thirties. Winterkilling was slight.

Ponderosa pine grew well. It established only low survivals, however, and suffered further losses between the ages of 5 and 10 years. Thereafter, very few trees were lost. Winterkilling was slight. Winter burning, or browning, of needles has become very prevalent since 1946. In some cases all the needles became discolored and many were killed. The trees have recovered from this injury but have undoubtedly been weakened by it to some extent. Ponderosa pine is subject to injury by the Nantucket pine moth *(Rhyacionia frustrana)*. Despite its low establishment survivals, the species is considered one of the best for shelterbelt plantings. The tree's clear-stemmed habit of growth makes it suitable for planting in interior rows, preferably the second or third row of either the windward or the leeward half.

Red pine, data on which are limited to zones 1 and 2, made good growth but survived in low percentages only. Heavy losses occurred after the first 5 years of growth. Winterkilling was recorded only in zone 1 and then only at 10 years of age. Studies made by the writer have indicated that this species develops only a very shallow root system and consequently is highly subject to loss caused by the frequent surface-moisture shortages of the northern Great Plains (fig. 11).

Scotch pine showed good growth progress but established only

[8] In addition to observations made within the study period, 1916–46, this section includes some observations on winter burning, or browning, of conifer foliage, a type of injury which has become pronounced since 1946.

FIGURE 11.—Red pine (foreground) severely injured by drought. The jack pine growing beside it shows no injury.

FIGURE 12.—A very successful Scotch pine planting 13 years old, northeast of Whitewater, near the northern boundary of Montana.

low survivals except in an occasional planting (fig. 12). Particularly heavy losses took place during the drought years of the middle thirties. Winterkilling was not recorded. This pine cannot be recommended for planting on dry-land sites.

Redcedar includes the eastern and western species. These species became mixed in many shelterbelts, through replacement planting. The limited data show good growth and survivals. The species have recently proved highly subject to winter burning of foliage. This has frequently killed all the needles on the growth of the past one or two seasons and in some plantings has killed all the needles of the entire tree. Killing back of terminal growth sometimes has resulted from this injury, and infrequently all trees have been killed. Trees protected from the north and west winter winds have seldom suffered this type of injury. Western redcedar is native throughout the northern Great Plains, and the eastern species is native at the extreme eastern edge of the area. Redcedar is one of the easiest conifers to establish, and is recommended for planting in the outside leeward row. Redcedar plantings, in addition to serving effectively for shelter, greatly add to the beauty of the farm home (fig. 13).

FIGURE 13.—Redcedar is an excellent shelterbelt tree and greatly adds to the appearance of the farm home.

Black Hills white spruce showed good growth and also fair establishment survivals, but suffered heavy losses after 5 years of growth. Additional heavy losses took place during the drought years of the middle thirties. Winterkilling was very slight. Better responses were found in zones 1 and 2 than in zone 3. Moderate winter burning of foliage has become prevalent in recent years.

Planting of the species should be confined to sites receiving supplemental moisture.

Blue spruce grew well and maintained a high percentage of its

FIGURE 14.—Blue spruce, an effective shelterbelt tree, forms a beautiful background for the garden (*A*) and the drive to the farmhouse (*B*). Both these examples are in zone 1.

establishment survivals. It was free from winterkilling but has suffered some winter burning of foliage in recent years. The species did better in zones 1 and 2 than in zone 3. It is an effective shelterbelt tree on the more moist sites and makes beautiful backgrounds at the farm home (fig. 14).

Western white spruce was used only in 1921 and 1927. It grew well, but its mortality was heavy after the first 5 years. No winterkilling was observed. This species should be planted only on sites receiving supplemental moisture.

Deciduous Shrubs

Data on Dahurian buckthorn are too limited to permit any conclusions. Growth and survival at 5 years of age were satisfactory. The wood is extremely brittle and is highly subject to breakage by wind and drifted snow. Breakage has occurred where the buckthorn was planted in either windward or leeward rows. This species is a prolific bearer of seed, which hangs on the trees and is readily eaten by birds during the winter months. In common with all other buckthorns, this species acts to some extent as the alternate host of crown rust of oats and therefore should not be planted in commercial oat-growing areas.

Silver buffaloberry made its maximum growth between the fifth and tenth years. Its survivals declined rapidly after the tenth year and were low at 25 years, the loss being most severe in zone 3. Considerable winterkilling was present after 15 years. The species was found to be highly susceptible to the heart rot fungus *Fomes ellisianus* when grown under cultivation. Severe wind breakage resulted from infection with this fungus. Silver buffaloberry is native throughout the region, growing on north and east sides of hills, on bottoms, in ravines, and sometimes on the open prairie. Under natural conditions it spreads by root suckers, but very little root suckering takes place under cultivation.

Chokecherry survivals declined after 10 years but remained fairly high through the twenty-fifth year. This species was above average among the shrubs as to freedom from winterkilling. In recent years, infection with X-disease virus has led to losses in both native and planted stands in that part of North Dakota lying immediately east of the study area. The species suckers profusely and forms dense thickets on the better sites. It is suitable for planting in either windward or leeward rows but, because it acts as a carrier of the X-disease virus, should not be used in shelterbelts close to stone-fruit orchards. In figure 15 chokecherry grown under limited irrigation is shown in contrast with chokecherry grown on dry land.

Tatarian honeysuckle was not used in the shelterbelt project until 1939. The limited data available indicate that it may be one of the better shrubs, or even the best, for either the windward or the leeward outside row. It is seldom injured by insect pests, such as blister beetles and grasshoppers, which defoliate some other shrub species.

FIGURE 15.—*A*, Chokecherry 5 years old grown under limited irrigation from a well operated with a windmill; *B*, chokecherry (at right) from the same lot of nursery stock planted the same day at a distance of 100 feet and grown under dry-land conditions.

Tatarian maple, planted in 1920–25, made growth progress throughout the study period. Severe losses after 5 years prevented further extensive use. Winterkilling was heavy in some years. Although very suitable for ornamental purposes because of the attractive fall coloring of its foliage, the species cannot be recommended for shelterbelt use under dry-land conditions.

Siberian pea-tree made good growth progress and survived well throughout the period. Only minor winterkilling was noted. This

FIGURE 16.—Russian-olive is a very useful species for the outside leeward row on the more moist sites (*A*). On very dry sites it sometimes dies out almost entirely when planted in that position, as in the shelterbelt shown in *B*—in which Siberian pea-tree proved entirely hardy.

shrub proved to be highly subject to defoliation and terminal-growth injury by blister beetles and grasshoppers. It is easily broken down by livestock. In dry seasons, leaf fall frequently precedes the end of August. Despite these unfavorable factors, this is one of the better shrubs for planting in the outside windward row of a shelterbelt on all soils except those of a very sandy nature.

American plum made growth progress through the age 10 years, after which winterkilling was sufficiently severe to cause a reduction in average height at 15 years. Survivals declined rapidly between the ages 5 and 15 years. On the more moist sites this shrub suckers profusely and forms dense thickets.

Russian-olive showed growth progress in each 5-year period. Its survival, however, declined after 5 years and dropped to less than 50 percent at age 25 years, being poorest in zone 3. Considerable winterkilling was recorded each period, but this appears to have increased only slightly with age. The shrub is broken down frequently by drifted snow and occasionally by gusty winds or early-fall wet snow or sleet storms. In wet falls, its indeterminate habit of growth frequently results in failure of the wood to mature and in failure to set terminal buds. Heavy killing back may result. Its branching habit makes it an excellent choice for the outside row on either the windward or the leeward side (fig. 16). Snow breakage may be heavy some years on trees planted in leeward rows. Russian-olive responds very favorably to irrigation, but it should not be irrigated between the middle of August and the time when the current growth is checked by killing frosts.

FACTORS AFFECTING RESULTS

The results shown in table 4 and figures 6, 7, and 8 were affected by many factors. Factors which affected results in all parts of the study area include distance between rows, number of rows composing the planting, care given to plantings, moisture conditions, exposure, and slope. Factors of a local nature include hail, wind, snow, livestock, insect pests, disease-causing agents, suppression, rabbits, mice, fire, drifting soil, and flood. While occasionally an individual factor, such as fire, was responsible for the results obtained, more frequently two or more factors combined to produce the end results; for example, neglect of weed control caused the trees to become weak and in this susceptible condition they were attacked by insects. Table 5 shows for four deciduous trees, two coniferous trees, and three deciduous shrubs, those which were rated the most promising on the basis of such characteristics as frost hardiness and drought resistance, the row spacing, the belt width, and the type of cultivation with which the best average growth in height and crown spread, the highest percentage free of winterkilling, and the highest survival were associated.

TABLE 5.—*Row spacings,*[1] *belt widths, and types of cultivation which gave the best results as to growth, freedom from winterkilling, and survival of species recommended for shelterbelt planting on the northern Great Plains*

Item	Deciduous trees				Coniferous trees		Deciduous shrubs		
	Green ash	Box-elder	American elm	Siberian elm	Ponderosa pine	Blue spruce	Common chokecherry	Siberian pea-tree	Russian-olive
ROW SPACING									
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Height	13–15	6–8	6–8	13–15	9–12	9–12	6–8	6–8	13–15
Crown spread	13–15	13–15		13–15		([2])	6–8	13–15	13–15
Freedom from winterkilling	13–15	13–15		9–12		([2])	9–12	([2])	13–15
Survival	6–8	6–8	9–12	9–12	6–8	6–8	6–8	6–8	13–15
BELT WIDTH									
	Rows	*Rows*	*Rows*	*Rows*	*Rows*	*Rows*	*Rows*	*Rows*	*Rows*
Height	1–6	1–6	7–12	1–6	1–6	1–6	7–12	([2])	1–6
Crown spread	([2])	1–6	7–12	1–6			7–12	([2])	1–6
Freedom from winterkilling	1–6	1–6	([2])	7–12			([2])	([2])	1–6
Survival	7–12	([2])	7–12	1–6	7–12	7–12	7–12	7–12	1–6
TYPE OF CULTIVATION									
Height	Clean	Clean	Clean	Clean	Weedy	Soddy	Clean	Clean	Clean.
Crown spread	Clean	Clean	Clean	Clean	Soddy	Soddy	Clean	Clean	Clean.
Freedom from winterkilling	Clean	Clean	Weedy	Clean	([2])	([2])	Clean	Clean	Clean.
Survival	Clean	Clean	Clean	Clean	Clean	Clean	([3])	Clean	Clean.

[1] For the different row spacings represented here, the approximate spacings of trees or shrubs within an interior row were generally as follows: 13 to 15 feet, 6 to 8 feet; 9 to 12 feet, 6 feet; 6 to 8 feet, 4 to 6 feet. Trees or shrubs were planted 3 or 4 feet apart when used in an outside row.

[2] Results did not differ appreciably.

[3] Results did not differ appreciably between the clean and weedy types.

Row Spacing

The most promising deciduous trees prevailingly grew best and suffered least winterkilling where they had been planted 6 to 8 feet apart in rows 13 to 15 feet apart. However, the crown-spread growth of trees in rows 15 feet apart was not sufficient to form a closed canopy; also, row spacings of 13 to 15 feet appeared less conducive to high survival than row spacings of 12 feet or less with tree spacings of 6 feet or less.

The high mortality of conifers practically eliminated spacing as a factor in results with conifers. Prevailingly, ponderosa pine and blue spruce made their best height growth where they had been planted in rows 9 to 12 feet apart and survived best in rows 6 to 8 feet apart. The very limited data available on crown-spread growth and freedom from winterkilling of conifers do not show any influence of row spacing.

A row spacing of 6 to 8 feet gave the best overall growth and survival of chokecherry and the best height growth and survival of Siberian pea-tree; one of 9 to 12 feet favored freedom from winterkilling of chokecherry; and one of 13 to 15 feet favored crown-spread growth of Siberian pea-tree and gave best results in all respects with Russian-olive.

Row spacings of about 12 to 15 feet permit maximum growth development of trees and shrubs and also permit the use of ordinary farm machinery for cultivation during the first 2 or 3 years.

Some suppression of certain species was found in plantings in which the trees were spaced 4 by 8 feet and trees of all species maintained high survivals. When boxelder, Siberian elm, poplars, and willows were planted in such spacings and maintained satisfactory growth and survival they either overtopped and stunted or "pushed out" the slower-growing trees in the same rows or in adjacent rows. Heavy losses suffered by the poplars and willows during their early years greatly reduced the suppression to which they could subject other trees.

The data for the various spacing classifications tend to support the findings of other investigators. Munns and Stoeckeler *(16)* concluded:

> Considering all factors and giving special consideration to opinions of farmers, there seems no reason under prevailing conditions for adopting spacing any wider than 10 or 12 feet between rows. This appears satisfactory throughout most of the shelterbelt zone. Not a single farmer interviewed desired a spacing wider than 14 feet.

Scholz *(17)*, in a study of the causes of decadence in old groves in North Dakota, compared the survivals of trees between the ages of 26 and 40 years in narrow spacings (8 to 40 square feet per tree) with those in wide spacings (48 to 64 square feet per tree), on light and on heavy soils. He found that on light soils 93 percent of the trees were living and healthy in the narrow-spaced groves, compared with 71 percent in the wide-spaced ones. On heavy soils, 75 percent of the trees were surviving in the narrow-spaced groves and 70 percent in the wide-spaced ones.

Ware *(21)*, on the basis of a survey of shelterbelts and other

planted trees in South Dakota, recommended a spacing of 6 to 8 feet between rows for the State in general and one not to exceed 12 feet for the driest areas in the western half of the State.

Number of Rows

Results obtained with the species rated the most promising were studied with reference to three ranges of belt width—1 to 6 rows, 7 to 12 rows, and more than 12 rows. The best overall growth and freedom from winterkilling for green ash and boxelder were associated with belt widths of 1 to 6 rows, also the best overall growth and survival of Siberian elm. The best overall growth and survival of American elm, survival of green ash, and freedom from winterkilling of Siberian elm were associated with belt widths of 7 to 12 rows. Differences favoring the 7-to-12-row width over the 1-to-6-row width were slight and did not offer conclusive evidence.

The very limited data for the two coniferous trees show that ponderosa pine and blue spruce made their best height growth in belts of 1 to 6 rows and survived best in belts of 7 to 12 rows.

Russian-olive did best, in all respects, in belts 1 to 6 rows wide. This shrub was usually planted in the first row of deciduous species on the leeward side—a position to which more drifting snow penetrates if the belt is narrow. Chokecherry grew and survived slightly better, and Siberian pea-tree survived slightly better, in 7-to-12-row than in 1-to-6-row belts. It cannot be said, however, that results with these shrubs show any decided preference between these ranges of width. This is explained by the fact that these shrubs were usually planted in the first row on the windward side, where availability of moisture from snowdrifts was not affected by belt width.

Variation in planting-site exposure, and location of farm buildings with reference to section lines, prevented any determinations as to number of rows of trees and shrubs necessary for adequate winter protection. In general, plantings of 5 to 10 rows can give adequate winter protection except on the most severely exposed sites, and such plantings are more likely to succeed than those having larger number of rows. Drifted snow, a source of beneficial moisture, must accumulate in all rows if the trees are to survive extended drought periods.

Cultivation and Other Care

The cultivation and other care given the shelterbelt plantings varied greatly. Some of the trees and shrubs were planted in sod or on very soddy land. This resulted in heavy to complete loss the first season. Only a small percentage of the shelterbelts were kept free of competitive weeds or had clean-cultivated strips maintained around them each year to prevent entrance of weeds, sod, and fire. Dead or injured limbs were seldom removed except in a few plantings in which all branches were removed to a height of

several feet. Such severe pruning permitted wind and snow to pass through the belts and encouraged weed growth.

The plantings were grouped in three classes according to type of cultivation: (1) Clean—in which weeds and other foreign growth were practically absent; (2) weedy—in which heavy competitive weed growth was present as a result of insufficient cultivation or none; and (3) soddy—in which cultivation was omitted for many years. How the nine species rated most promising grew and survived under these three types of cultivation is shown in table 5. Aside from height and crown-spread growth of coniferous species and freedom from winterkilling of American elm, the best results were obtained where clean cultivation was practiced (fig. 17). This finding agrees with results of an earlier study by the author *(7)*. Sod or weeds, (fig. 18) can compete seriously with trees for moisture. Growth and survival of deciduous trees and shrubs were generally better in weedy plantings than in soddy plantings. No explanation can be offered for the fact that the limited data available for ponderosa pine and blue spruce indicate better height and crown-spread growth under weedy or soddy conditions than under clean cultivation.

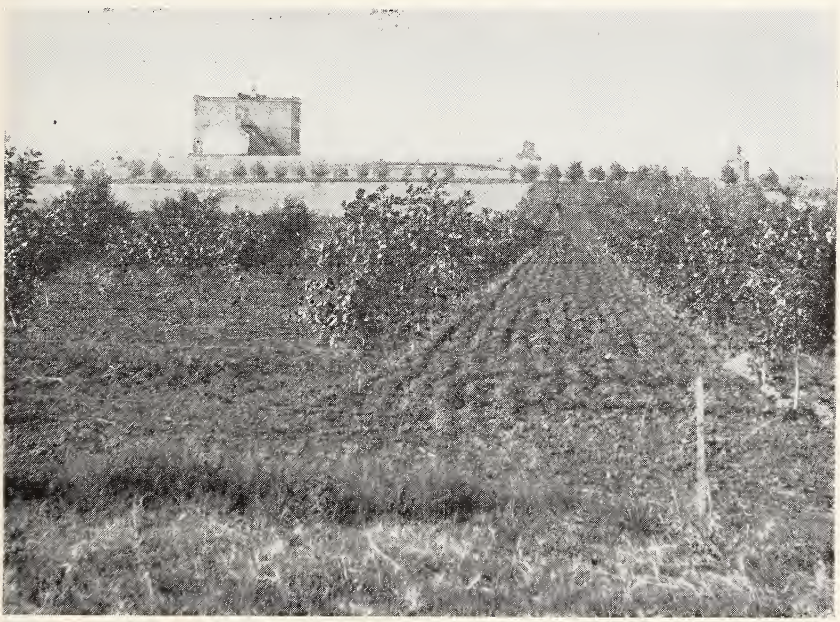

FIGURE 17.—Clean cultivation favors best growth and survival of deciduous trees in the northern Great Plains. This 4-year-old shelterbelt, protecting the building and grounds of a public school in North Dakota, had been well cultivated each year.

The duckfoot cultivator gave excellent results in shelterbelt plantings. The spring-tooth harrow was very useful because it has inside wheels and a single section of it can be used when the

FIGURE 18.—Weeds can compete seriously with conifers. Clean-cultivated conifers in view *A* were making excellent progress in 1939 when the weedy conifers in view *B*, only 5 years older, were dying out except in a slight depression which received runoff water.

space between rows becomes too narrow for the full-width harrow. Some farmers contributed to the success of their shelterbelts by adapting farm machinery for use in cultivating the planted areas. The home-made cultivator shown in figure 19 killed weeds very effectively and did not expose much of the subsurface moisture.

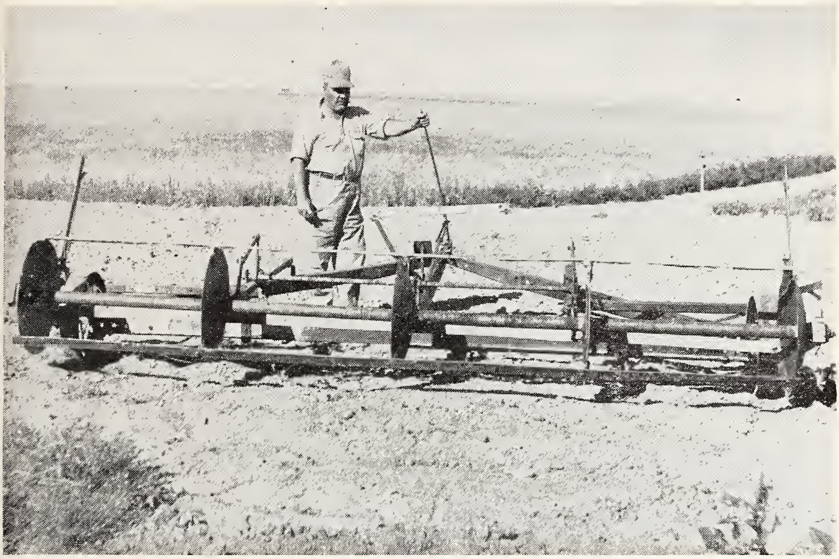

FIGURE 19.—This cultivator was devised and made at home by a farmer who was interested in keeping his young tree planting free of weeds. The farmer planned to construct a narrower implement after a few years' tree growth had reduced the open space between rows.

(However, it left the soil smooth, which might create danger of blowing.)

A type of cultivation which proved very undesirable for shelterbelts is continued use of a single-disk cultivator. This forms ridges against the trees and depressions between rows. Very heavy runoff resulted from such cultivation on sloping land and led to high mortality.

Mulch of hay, straw, or manure was applied to control weeds in some plantings, but the data for this type of weed control are too limited to permit any definite conclusions and are not tabulated. The growth and survival of trees in mulched plantings were extremely good in some instances and extremely poor in others. Mulch was found to harbor rodents which sometimes injured the trees by girdling them at the ground line—or even, during winters of heavy snowfall, for several feet above the ground line.

MOISTURE CONDITIONS

In the northern Great Plains area, rainfall averages are at or below the minimum needed for growing trees successfully. Also, as has been stated, much of the growing-season rainfall comes in small showers or in storms of high intensity—types of rainfall which do not greatly benefit trees on upland sites.

The severe droughts prevalent in 1931–36 had an adverse effect on growth and survival of shelterbelt trees, causing heavy losses

FIGURE 20.—Irrigated shelterbelt 10 years old growing well on a clay soil in a locality in northern Montana where this soil, under dry-land conditions, permits only poor to fair results with planted trees.

on all soil types from sand through to clay. Shelterbelt cancellation percentages are discussed with reference to drought on page 15, and first-year survival of conifers and of deciduous species is discussed with reference to precipitation on pages 15 and 17.

Much neglect of shelterbelts resulted from the droughts of the thirties (and the concurrent depression). Within the drought period many farmers in the project area lost their farms by foreclosure and few of those who managed to stay on cultivated their shelterbelts or gave them other care. Neglect exposed the trees to drought injury and also, in some localities, to severe injury by heavy insect infestations present during the middle and late thirties. On many northern Great Plains farms having shelterbelt plantings no other "green crop" could be seen during the summer months of the drought years. Because of the scarcity of grass or other forage during those years, fences were taken down from around many shelterbelts to permit livestock to browse the few green leaves present. Passing of farms to Rural Resettlement Administration ownership during the drought years in many cases resulted in moving away of farm buildings and taking down of shelterbelt fences. In such cases the plantings became part of the open range and the trees were soon destroyed by livestock.

Where irrigation water was available it solved many of the tree-growing problems and in most cases insured success (figs. 15, 20). In some cases an area chosen for a planting was already receiving runoff or other waste water from an area of higher elevation, and in other such supplemental water was diverted onto the shelter-

belt area for the benefit of the trees. Dikes constructed through tree plantings on sloping land proved very beneficial in holding rain water until it was absorbed by the soil. On a few sites, the meager rainfall of the northern Great Plains was supplemented by moisture from a high water table. Strikingly good results were obtained on such sites (fig. 21).

Exposure, Slope, and Soil

Exposure and slope exerted an important influence on response

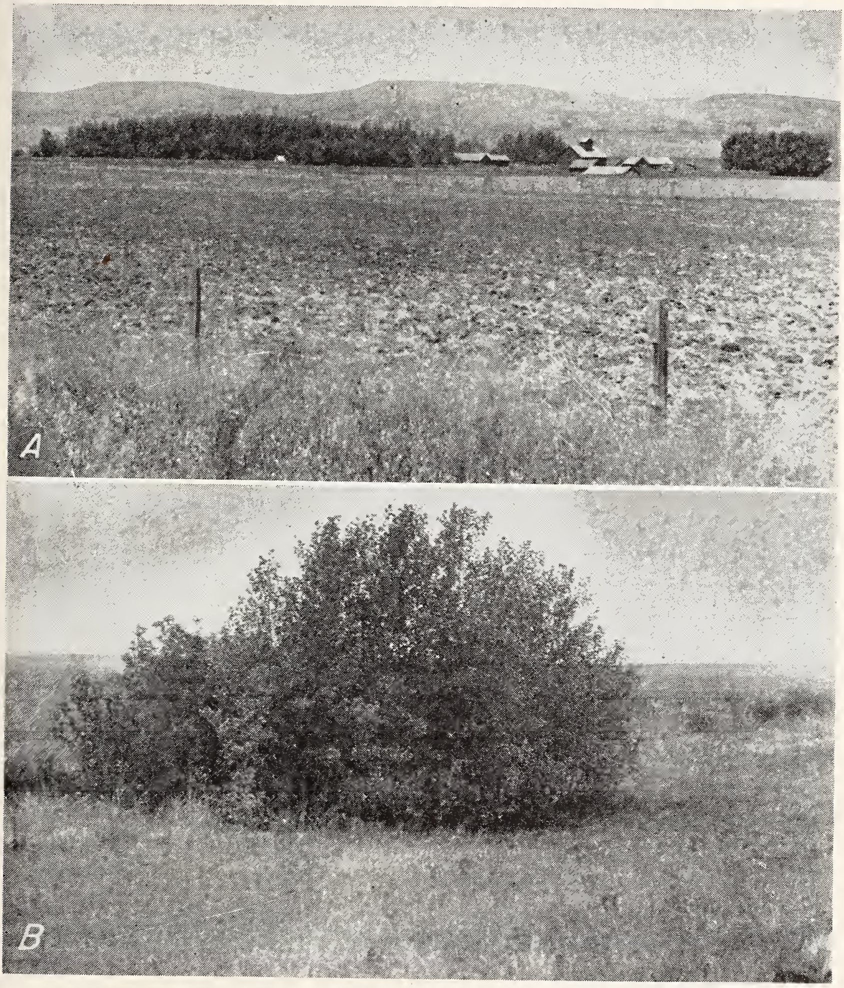

Figure 21.—*A*, Here 100-percent survival and an average tree height of 50 feet at 15 years were made possible by a high water table; *B*, this shelterbelt, grown under conditions otherwise comparable to those of the belt shown in *A*, had supplemental water only for brief periods and then only in the depression at the center of the view.

of shelterbelt trees (fig. 22). More plantings succeeded on level land or on land sloping gently to the north or the east than elsewhere. Southern exposures proved the least favorable. The native growth on upland sites in the project area is largely confined to north and east slopes, little or none of it being found on slopes having a southern exposure.

FIGURE 22.—Exposure and slope have influenced tree responses in these shelterbelts planted on similar soil 2 miles apart. The belt in *A* is on a gentle north slope and has excellent survival. The belt in *B* is on a sharp south slope. Although planted the same day as the other, with stock of the same source, and given better early care, it has suffered heavy losses and severe killing back.

Depressions in which runoff water collected or through which it passed usually supported better growth and survival than other locations. However, it was frequently found that trees had made better growth and maintained higher survivals on hilltops or on slopes than they had at the bottoms of slopes.

Soil type undoubtedly played an important part in the results with some plantings (figs. 23, 24). In many instances a planting

was made on a site where several soil types occur in mixture and very sharp differences in type can be picked out by observing the growth and behavior of the trees. Soil types of the project area have not been studied in such detail that any definite conclu-

FIGURE 23.—Differences in soil type and other site factors explain the superiority in both growth and survival of trees of all species in the right foreground. They explain also the inferiority in both respects of the trees at the bottom of the slope as compared with those higher up.

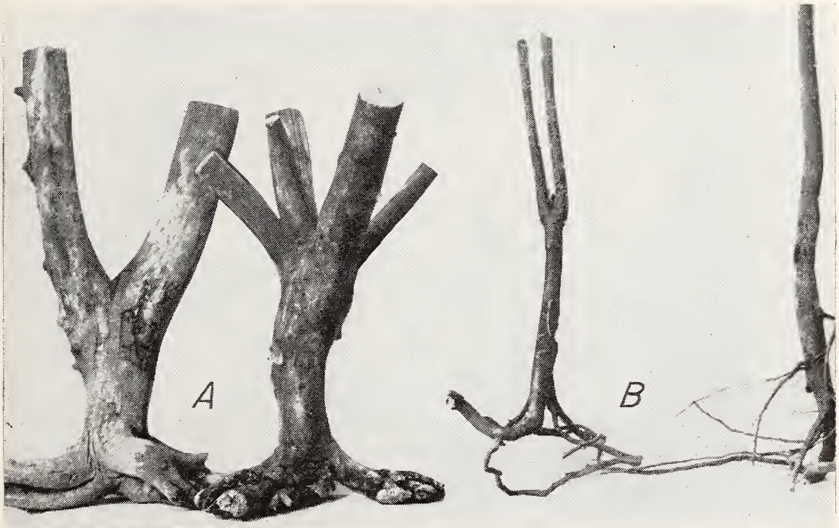

FIGURE 24.—Roots of 10-year-old Northwest poplar (*A*) and green ash (*B*) which failed to penetrate a hardpan layer closely underlying the depth of planting. The Northwest poplar died; the green ash made only about as much growth as it would normally have made in 2 years.

sions can be drawn regarding the suitability of each for tree culture, except that the clay soils are less favorable than the other types for growing trees under strictly dry-land conditions.

Disappointing results were obtained on soil enriched with manure as a result of having been used over long periods for corrals, hog lots, or strawstacks. Plantings made on such soil invariably failed in the first dry season, even where good survival and growth were obtained immediately outside the manured areas.

Ownership and Fencing

Prevailingly, chances that a farm shelterbelt will be given proper care and attention are greatly lessened if the farm ceases to be operated by the owner. Evidence of this appears in figure 25, in which the shelterbelts which were active and those which were canceled, respectively, at each of the 5-year age intervals are classified in regard to the farm ownership factor—that is, in regard to the farm's operation by the owner, operation by a renter, or abandonment. The owner-operation percentage was much higher for active than for canceled plantings of every age group. The abandoned-farm percentage was very similar for both series except that it was much larger for the canceled than for the active plantings in the 30-year group.

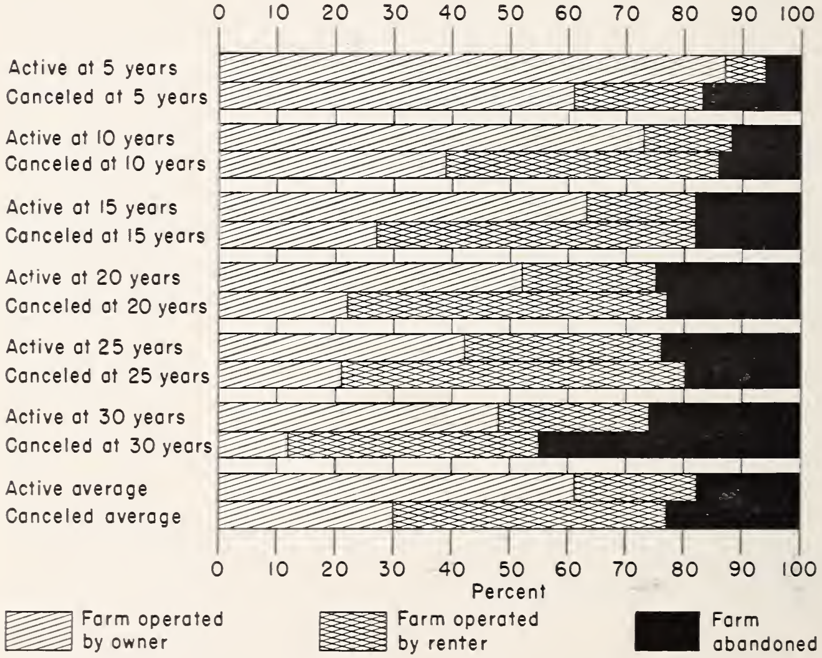

Figure 25.—Distribution of active and of canceled plantings by farm's ownership status, at ages 5 to 30 years.

Farm ownership status changed during the study period in many instances. By the time the shelterbelts were 20 years old, the percentage on farms operated by the owners had diminished by about 35 and the percentage on abandoned farms had increased by about 20.

For both canceled and active plantings the owner-operation percentage decreased as age increased to 25 years, reflecting consequences of the severe droughts and economic depression of the thirties. On an average about 60 percent of the active plantings were on owner-operated farms, as compared with about 30 percent of the canceled ones.

Shelterbelt plantings protected from livestock by fencing amounted to 78 percent of the total at 5 years but to less than 60 percent at 20 years and later.

Local Adverse Factors

Local adverse factors, although generally minor, in many instances determined the end results with a given tree planting. Table 6 shows the maximum percentages of shelterbelts in which, at any one periodic inspection, trees or shrubs of individual species

Figure 26.—Ponderosa pine row, in northwestern South Dakota, completely defoliated by grasshoppers.

TABLE 6.—*Maximum percentages of shelterbelts in which, at any one periodic inspection, trees or shrubs of individual species or species groups were found to have been affected by local factors unfavorable to growth and survival*

Species	Shelterbelts in which injury due to indicated factor was found						
	Hail	Wind and snow	Livestock	Insects[1]	Disease-causing agents[2]	Suppression	Others[3]
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Deciduous trees:							
Green ash	5	4	17	28	1	11	1
Boxelder	4	2	13	26	1	3	1
Plains cottonwood	7	0	4	4	4	0	0
American elm	10	5	70	40	0	4	20
Siberian elm	4	20	9	4	5	2	50
Hackberry	6	3	6	6	0	0	10
Honeylocust	0	0	0	20	0	0	0
Northwest poplar	6	2	16	29	12	0	1
Other poplars	0	0	3	0	3	0	0
Willows	2	0	7	5	2	26	0
Coniferous trees:							
Jack pine	0	0	0	0	0	0	0
Ponderosa pine	0	0	25	0	0	0	0
Red pine	0	0	0	0	0	0	0
Scotch pine	0	33	33	0	0	0	0
Redcedar	4	0	2	0	0	0	0
Black Hills white spruce	0	50	0	50	0	12	0
Blue spruce	0	25	0	7	0	0	0
Western white spruce	0	50	50	0	0	0	0
Deciduous shrubs:							
Dahurian buckthorn	6	0	0	6	0	0	0
Silver buffaloberry	7	27	7	20	100	6	0
Common chokecherry	3	2	14	26	0	18	0
Tatarian honeysuckle	25	0	0	0	0	0	0
Tatarian maple	3	5	50	0	0	100	0
Siberian pea-tree	5	2	22	47	0	2	1
American plum	0	5	5	2	0	0	0
Russian olive	6	6	7	18	1	8	1

[1] Grasshoppers, blister beetles, larvae of the cecropia moth (*Samia cecropia*), webworms, and cankerworms defoliated deciduous species. Grasshoppers defoliated and "barked" conifers in the drought years. Red spiders infested conifers. The Nantucket pine tip moth infested ponderosa pine. Borer infestation was found in green ash, Siberian elm, and poplars. Bark beetles were found on American elm, and the vagabond poplar gall insect (*Mordwilkoja vagabunda*) on poplars.

[2] Leaf rust was found on green ash, fungus infection in poplars and Siberian elm, heart rot in silver buffaloberry, unidentified diseases in Russian-olive, boxelder, and willows.

[3] Rabbits, mice, fire, drifted soil, and flood.

or species groups were found to have been injured, infested, infected, or otherwise affected by one or more unfavorable local factors. Hailstorms had stripped the bark from trees to an extent causing them to die to the ground. Wind and snow had broken tops or stripped lateral branches. Livestock had browsed foliage, rubbed stems, and broken trees down; in addition, they tended to pack the soil by trampling and thus make it less receptive to water. Insects had defoliated trees, injured their terminal growth, tunneled stems, barked stems, and caused premature leaf drop (fig. 26). While disease had not been serious, heart rot had resulted in the breaking down of silver buffaloberry, cankers were present on parts of the stems of trees of poplar species, and rust on leaves of green ash and poplars had sometimes caused early drop. Suppression resulting from placing slower- or lower-growing species between faster- or taller-growing species had retarded growth and in some cases had caused death. Rabbits in some instances had completely girdled tree stems, causing the trees to die back to below the injury; mice, in mulched plantings, had girdled stems at the ground line. Fire had caused some injury and death. Drifted soil had accumulated in some shelterbelts to depths as great as 8 feet.

Widespread damage by livestock resulted from lack of adequate fencing of shelterbelts, discussed in earlier sections. Only a small percentage of farmers practiced control measures against insect and rodent pests. The greatest effort in the line of pest control was directed against jack rabbits.

CONCLUSIONS

In the northern Great Plains area scantiness of precipitation tends to make the growing of farm shelterbelts hazardous under dry-land conditions. By following certain well-defined practices, however, most farmers can grow trees satisfactorily to ages of 20 to 30 years or more, thus gaining protection for farm buildings, livestock, orchards, and gardens. Briefly, the principles of shelterbelt growing in the area are these:

1. Selection of site. If there is any choice as to site, level land or gently sloping land having a northern or eastern exposure should be preferred. Sites sloping toward the south are the least desirable. Heavy soils, alkaline spots, and areas which have been heavily manured for many years should be avoided as far as possible.

2. Land preparation. The planting site should be summer-fallowed the year before the trees are planted, so that as much moisture as possible may become stored in the soil. The land should be thoroughly freed of live sod before trees are planted. High survivals and vigorous growth the first year are requisites for a successful shelterbelt.

3. Selection of tree and shrub species. For the average upland site, species giving good promise are Siberian pea-tree, Russian-olive, chokecherry, and Tatarian honeysuckle for the outside row

of the windward half; green ash, boxelder, Siberian elm, American elm, and ponderosa pine for interior rows; and redcedar for the outer leeward row. Where rainfall is supplemented through runoff or irrigation, poplar, willow, blue spruce, Black Hills white spruce, and Scotch pine give satisfactory results. A good guide, though not necessarily a sure one, is the observed behavior of different species in the locality.

4. Number of rows. Plantings 5 to 10 rows in width can give adequate winter protection except on the most severely exposed sites and have more chance for success than plantings containing larger numbers of rows. Drifted snow, a source of beneficial moisture, must accumulate in all rows if the plantings are to survive extended drought periods.

5. Spacing. A distance of 12 to 15 feet between rows gives very satisfactory results and permits cultivation with ordinary farm machinery for the first 2 or 3 years. Row spacings wider than 15 feet should not be used; very few species will ever develop sufficient crown spread to close the canopy if planted in rows so far apart. A distance of 6 to 8 feet between trees in the row permits normal growth without a high degree of suppression.

6. Planting operation. Regardless of whether planting is done by hand or with machinery, the depth of the hole or trench should be sufficient to prevent bending of roots. Care must be exercised to place all roots at the proper depth and pack the soil firmly around them. Shallow-planted or poorly planted trees will never make a successful shelterbelt. Planting trees in a plow furrow and then covering their roots by plowing another furrow is not a good practice.

7. Replanting. All trees which fail to become established should be replaced the second year. Fail spots cannot be replanted successfully after an interval of several years. Trees of the first planting, after a few years of successful growth, offer too much competition to younger trees for moisture.

8. Cultivation. Clean cultivation should be practiced as long as it is possible to work between the trees or until the tree crowns shade out competitive undergrowth. Farmers should be prepared to adapt their farm machinery for tree-cultivation purposes and must be prepared to use narrower implements as the trees increase in crown spread. Recommended implements are the duckfoot cultivator; the spring-tooth harrow, a single section of which can be used when the space between rows becomes too small for the harrow's full width; and home-made cultivators of the type shown in figure 19. Alternate use of a home-made cultivator of this type and the duckfoot cultivator would prove very satisfactory. Continued use of a single-disk cultivator should not be practiced.

9. Protection of trees. All shelterbelts should be fenced—to keep livestock out, not to keep them in. Livestock injure trees directly by browsing and trampling them and also tend to pack the soil by trampling and thus make it less receptive to water. A cultivated strip should be maintained along each side and each end of a shelterbelt to keep out weeds, sod, and fire. Measures should be

taken to control injurious insects and prevent injury by rodents A mulch of hay, straw, or manure should not be applied unless it is needed to control erosion, because such a mulch harbors rodents which may girdle the trees.

10. Supplemental water. Every effort should be made to supply the trees with water supplemental to rainfall, either by irrigating or by diverting runoff or other waste water onto the planted area. On a sloping site, it is advisable to construct dikes through the planting to hold water in place until it can percolate into the soil.

SUMMARY

An investigational and demonstrational shelterbelt project was started in 1916 on the northern Great Plains, an area of more than 200,000 square miles including roughly the western halves of North and South Dakota, the eastern and central parts of Montana, and northeastern and north-central Wyoming, by the United States Northern Great Plains Field Station, Mandan, N. Dak., and cooperating farmers. This area, most of which is almost treeless in nature, is subject to severe winter cold and severe summer heat; for example, temperatures recorded within a 6-month period at two stations in the North Dakota part less than 100 miles distant from each other had a range of 181° F. Annual precipitation as recorded in three north-south zones of the area over periods of 11 to 33 years during the period 1914–46 averaged 13.62 to 16.16 inches, and the annual frost-free period for these zones averaged 127 to 139 days.

The Mandan station furnished instructions for selecting shelterbelt sites and for preparing the land. Members of the station staff prepared planting plans after inspection of the planting sites. Planting stock grown at the station and instructions for planting, care, and maintenance of shelterbelts were given to each cooperating farmer.

Plantings were located on sites varying widely in topography, exposure, and soil type. A large percentage of the sites were on uplands, owing to the fact that farm buildings are usually located on well-drained areas. In most cases the land had been kept in clean fallow the previous growing season. Plantings ranged in width from 1 to 12 or more rows, and space between rows ranged from 6 feet to 15 feet.

Species tested in the shelterbelts included 12 deciduous trees, 8 coniferous trees, and 8 deciduous shrubs. Conifers, whenever used, were located in outer leeward rows. Shrubs were planted in the outside row on the windward side and frequently in the first row of deciduous species on the leeward side.

For the period 1916–42, plantings made totaled 4,670. Growth, survival, and (from the early thirties onward) winterkilling data were collected from the plantings at intervals of 5 years in their ages. On an average, 63 percent of the active plantings of the respective age intervals were visited each year. The data for ages 5, 10, and either 15, 20, 25, or 30 years were tabulated separately for the deciduous trees, conifers, and deciduous shrubs used.

First-year survival of deciduous species averaged more than 72 percent in all years except 1919 and the severe drought years 1934 and 1936. First-year survival of conifers was high only in years when rainfall was greater than normal or approximately normal rainfall was well distributed through the growing season.

When the data were summarized on the basis of division of the project area into three north-south zones, it was found that survival was generally somewhat poorer in the southern zone, the northern boundary of which coincided with that of South Dakota. Also, height growth of deciduous trees was somewhat less in this zone. The clay soils found over much of the southern zone apparently are less favorable than the lighter soils which prevail in the zones to the north.

Growth, survival, and freedom from winterkilling were affected by many factors including spacing, number of rows composing the planting, cultivation practices, moisture conditions, exposure, and slope. Local adverse factors included, among others, hail, wind, snow, livestock, insects, and disease-causing agents.

The influence of spacing and of belt width on the success of shelterbelt plantings was studied on the basis of data for the four deciduous trees, two coniferous trees, and three deciduous shrubs judged the most promising. A spacing of 13 to 15 feet between rows and 6 to 8 feet between trees in the row gave very satisfactory results. Such spacing permits normal growth without a high degree of suppression and permits use of ordinary farm machinery for cultivation during the first 2 or 3 years. Deciduous trees planted in rows 13 to 15 feet apart made the best growth and suffered the least winterkilling. These trees did not form a closed crown canopy when grown in rows 15 feet apart. They survived best in plantings having 12 feet or less between rows and 6 feet or less between trees. Deciduous species generally showed best responses in plantings of 1 to 6 rows. For coniferous species, best height growth was associated with belt widths of 1 to 6 rows and best survival with widths of 7 to 12 rows.

Best growth and survival were obtained under the system of clean cultivation—that is, cultivation which practically eliminated weeds or other foreign growth.

More plantings succeeded on level land or on land sloping gently to the north or east than elsewhere. Southern exposures proved the least favorable. Soil type undoubtedly played an important part in the results with some plantings; but soil types of the project area have not been studied in such detail that definite conclusions can be drawn regarding the suitability of each for tree culture, aside from the unfavorableness of the clay soils under dryland conditions. Plantings made on soil enriched with manure as a result of having been used over long periods for corrals, hog lots, or strawstacks invariably failed in the first dry season.

In the northern Great Plains rainfall averages are at or below the minimum needed for growing trees successfully, and much of the growing-season rainfall does not greatly benefit trees on upland sites because it comes in small showers or in storms of high intensity. Snow can be very beneficial to shelterbelt trees if it

drifts in the belt. Where irrigation water was available it solved many of the tree-growing problems and in most cases insured success. Runoff or other waste water flowing onto a shelterbelt site from land at higher elevation was likewise beneficial. The severe droughts prevalent in 1931–36 had an adverse effect on growth and survival of shelterbelt trees, causing heavy losses on all soil types from sand through to clay. In addition to this direct effect, the droughts caused many farmers in the project area to lose their farms by foreclosure. Prevailingly, chances that a farm shelterbelt will be given proper care are greatly lessened if the farm ceases to be operated by the owner.

At every age, the owner-operation percentage was much higher for the active plantings than for those which were canceled (that is, dropped from the active list because they had ceased to be possible sources of useful data).

Of the plantings made in the first 4 years of the project, more than 50 percent were canceled at the age of 5 years. For the planting years from 1920 to about 1930, progress in finding hardier species and better methods of planting and maintaining shelterbelts was reflected in a gradual decrease in such cancellations. At the height of the drought period in the middle thirties, cancellations at 5 years went beyond 45 percent. Fifth-year visitations of 1938–42 plantings were limited to 3 percent of the 1938 plantings and 71 percent of the 1942 plantings and resulted in cancellation of 3 percent of the 1942 plantings only. For the 27 planting years 1916–42, active shelterbelts averaged 78 percent at 5 years, 69 percent at 10 years, 66 percent at 15 years, 57 percent at 20 years, 41 percent at 25 years, and 32 percent at 30 years.

Methods for selecting, planting, and caring for trees are suggested which, if followed, will give reasonable assurance on most farms in the northern Great Plains of effective shelterbelt protection for many years.

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